

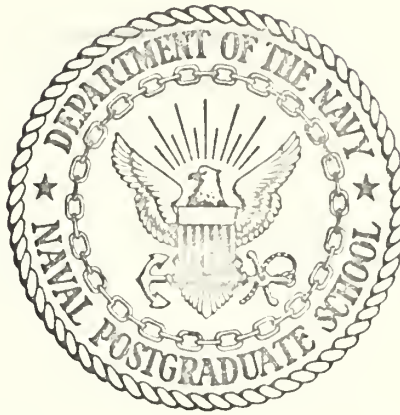
A FIXED-BASE VARIABLE-STABILITY
CARRIER APPROACH LANDING SIMULATOR
(CALS)

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NAVAL POSTGRADUATE SCHOOL

Monterey, California



THESIS

A Fixed-Base Variable-Stability
Carrier Approach Landing Simulator
(CALs)

by

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March 1972

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ABSTRACT

The following is a report on the design and construction of a fixed-base variable-stability simulator facility combined with the task of landing to a carrier or runway.

The solution was mechanized on a hybrid computer with the analog computer solving the equations of motion and the digital computer used for storage, control and graphics generation. The display was in the form of a computer-drawn picture on a graphics terminal. Control was by a simulated cockpit placed in front of the display and connected to the analog computer.

Dynamic validation was considered excellent with the modal periods of the simulated aircraft agreeing very closely with those of the actual aircraft.

The visual display was deemed very good as sufficient visual cues were provided to enable consistent landings by experienced pilots.

This project was undertaken not as a design of training aid but rather as a research tool for further studies in control systems, human engineering and aircraft dynamics.

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LIST OF SYMBOLS

| | |
|------------------------|---|
| b | Wing span, ft |
| C_D | Drag coefficient |
| C_L | Lift coefficient |
| $C_{L_{\dot{\alpha}}}$ | Lift coefficient due to rate of change of angle of attack |
| $C_{L_{\delta it}}$ | Lift coefficient due to elevator deflection |
| C_{L_Q} | Lift coefficient due to pitching |
| C_l | Rolling moment coefficient |
| $C_{l_{\delta a}}$ | Aileron control effectiveness derivative |
| $C_{l_{\delta r}}$ | Rolling moment coefficient due to rudder deflection |
| C_{l_p} | Damping in roll derivative |
| C_{l_R} | Rolling moment coefficient due to yawing |
| C_m | Pitching moment coefficient |
| $C_{m_{\dot{\alpha}}}$ | Angle of attack damping derivative |
| $C_{m_{\delta it}}$ | Elevator control effectiveness derivative |
| C_{m_Q} | Pitch damping derivative |
| C_n | Yawing moment coefficient |
| $C_{n_{\delta a}}$ | Aileron yaw derivative |
| $C_{n_{\delta r}}$ | Rudder control effectiveness derivative |
| C_{n_p} | Yawing cross derivative |
| C_{n_R} | Damping in yaw derivative |
| C_Y | Side force coefficient |

| | |
|--------------------|---|
| $C_{Y_{\delta a}}$ | Side force coefficient due to aileron deflection |
| $C_{Y_{\delta r}}$ | Side force coefficient due to rudder deflection |
| C_{Y_p} | Side force coefficient due to rolling |
| C_{Y_R} | Side force coefficient due to yawing |
| \bar{c} | Wing chord, ft |
| $F_{X_{aero}}$ | Aerodynamic force in X stability axis direction, lb |
| F_{X_s} | Total force in X stability axis direction, lb |
| F_{X_w} | Total force in X wind axis direction, lb |
| $F_{Y_{aero}}$ | Aerodynamic force in Y stability axis direction, lb |
| F_{Y_s} | Total force in Y stability axis direction, lb |
| F_{Y_w} | Total force in Y wind axis direction, lb |
| $F_{Z_{aero}}$ | Aerodynamic force in Z stability axis direction, lb |
| F_{Z_s} | Total force in Z stability axis direction, lb |
| F_{Z_w} | Total force in Z wind axis direction, lb |
| g | Acceleration due to gravity, 32.2 ft/sec ² |
| I_{xx} | Moment of inertia about X body axis, slug-ft ² |
| I_{xz} | Cross product of inertia, slug-ft ² |
| I_{yy} | Moment of inertia about Y body axis, slug-ft ² |
| I_{zz} | Moment of inertia about Z body axis, slug-ft ² |
| L | Rolling moment about body axis, ft-lb |
| L_s | Rolling moment about stability axis, ft-lb |
| M | Pitching moment about body axis, ft-lb |
| M_s | Pitching moment about stability axis, ft-lb |
| m | Mass of the aircraft, slug |

| | |
|---------------|--|
| N | Yawing moment about body axis, ft-lb |
| N_s | Yawing moment about stability axis, ft-lb |
| P | Rolling rate about body axis, rad/sec |
| P_s | Rolling rate about stability axis, rad/sec |
| \bar{P}_s | Normalized rolling rate about stability axis |
| Q | Pitching rate about body axis, rad/sec |
| Q_s | Pitching rate about stability axis, rad/sec |
| \bar{Q}_s | Normalized pitching rate about stability axis |
| q | Free stream dynamic pressure, lb/ft ² |
| R | Yawing rate about body axis, rad/sec |
| R_s | Yawing rate about stability axis, rad/sec |
| \bar{R}_s | Normalized yawing rate about stability axis |
| S | Aerodynamic reference area, ft ² |
| \dot{S}_x | \dot{X} |
| \dot{S}_y | \dot{Y} |
| \dot{S}_z | \dot{Z} |
| T | Thrust of aircraft, lb |
| V | Velocity of aircraft, ft/sec |
| X | X inertial coordinate of aircraft, ft |
| Y | Y inertial coordinate of aircraft, ft |
| Z | Z inertial coordinate of aircraft, ft |
| α | Angle of attack, deg |
| β | Angle of sideslip, deg |
| δ_a | Aileron deflection angle, deg |
| δ_{it} | Elevator deflection angle, deg |
| δ_r | Rudder deflection angle, deg |
| ϕ | Euler roll angle, deg |

| | |
|-----------------------|------------------------|
| ψ | Euler yaw angle, deg |
| θ | Euler pitch angle, deg |
| $(\dot{})$ | $d()/dt$ |

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I. INTRODUCTION

The purpose of this project was to construct a multiple task simulator, an inherent quality of which had to be the ease of its extension as a research tool to various real world problems that arise. In addition, the use of interactive computer graphics would be studied as a means of visual display for the simulator. The decision was made to design the simulator to the initial task of approach and landing to an aircraft carrier deck.

The hub of the simulator system is a hybrid computer, part digital, part analog. The analog computer solved the equations of motion while the digital computer was used for control, storage and graphic build-up. The display was handled by a graphics processor and terminal connected directly to the digital computer. Control of the simulator was through a simulated cockpit placed in front of the graphic display, with stick and throttle outputs tied directly to the analog. This then formed the control loop as diagrammed in Figure 1.

At the beginning, a decision on the allocation of equipment functions had to be made. Several all-digital moving-base simulators were already constructed [Ref. 1]. As space, money and time were limited, moving base was out of the question but a pure digital solution was not. On the other hand the department already had a "Mini Link" Simulator utilizing an all analog solution. However, due to the lack of non-linear equipment and the need for generating a visual perspective display, the pure analog solution could not be implemented. Then too, the digital solution was too slow for the needed integration and did not provide for a pilot-station computer interface. The obvious solution was the

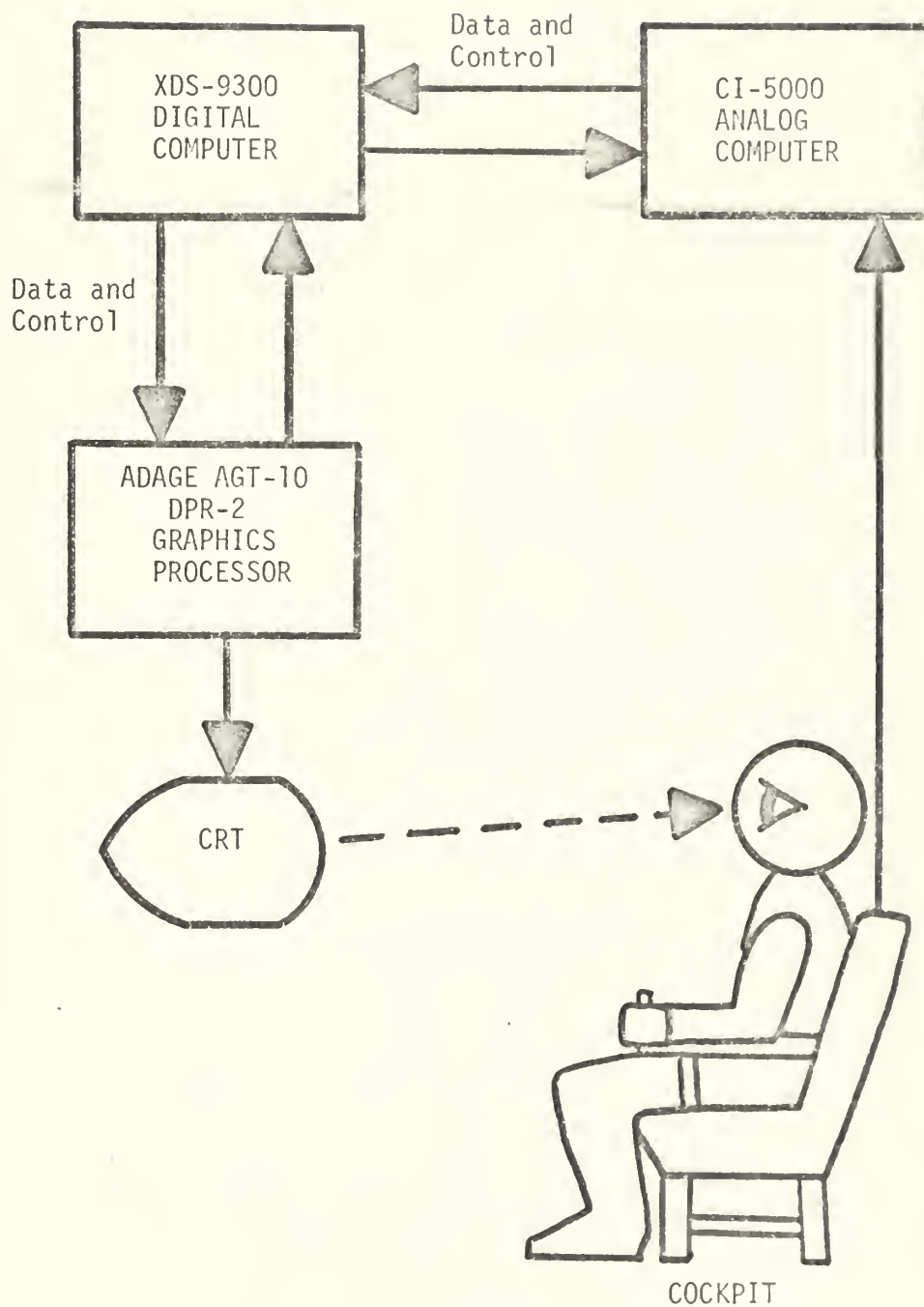


Figure 1. Lines of Communications.

hybrid computer. The non-linearities of the aircraft coefficients, the resolution of the forces and moments and the generation of the display would be tasked to the digital computer. The integration of the equations of motion and the interfacing would be done by the analog. In this manner the best features of both computers could be utilized.

The display would be a computer-drawn picture on a graphics terminal connected to the digital computer. Construction of the picture would be done by the digital computer while the display and refresh would be done by the graphic digital processor.

The "cockpit" was simply a seat and attached controls placed in front of the graphics CRT. Stick and throttle outputs from the cockpit were then fed directly into the analog computer, thus closing the control loop.

The design features incorporated into the Carrier Approach Landing Simulator (CALS) were:

1. Ability to change the aircraft being simulated
2. Capability of simulating non-linear aerodynamic data
3. Automatic scaling of the analog computer solution
4. Fixed-base inside-out display
5. Ability to expand or change the simulator task
6. Simplicity of setup and operation

II. THE SIMULATOR

The simulator is capable of accurately simulating vehicle dynamic response in conjunction with a dynamic inside-out display with its viewing plane affixed to the vehicle. The analog solution is updated at a rate of 18 samples per second which leads to excellent dynamic response. A new graphic display image is generated at the rate of 18 frames per second with a digital processor refresh rate of 40 frames per second. This leads to a display with virtually no flicker and in general very good graphic qualities.

The simulator was designed to accept the following inputs in the form of punched cards: the coordinates of the runway; the runway constants (glide slope and lens placement); the aircraft constants (eight, moment of inertia, wing area etc.); initial conditions of the problem (initial position, altitude and velocity) the maximum expected range of the state and control variables in the form of scale factors: and the aerodynamic coefficients of the simulated aircraft. The preparation of this data deck is outlined in Appendix F.

The simulator then processes this data, autoscales the analog computer based on the given and self-generated scale factors, sets the potentiometers of the analog and places the initial conditions on the proper integrators. Control of the simulator is then transferred to the pilot who responds as per the displayed instructions. At the completion of a run the simulator analyzes the landing and displays the results. This analysis includes sink rate at touch down, line-up, airspeed and type of landing (crash, bolter or arrested landing on a certain wire). At this time options are offered to either fly again with the same parameters, change the parameters or stop the program.

Besides these options, the operator can suppress printed output if desired, select a yaw damper (ON/OFF) and inhibit translational movement while flying the aircraft. Also, at the disposal of the operator, is an eight-channel strip recorder and an oscilloscope that are patched into the analog computer. This gives the operator the ability to output the time history of any variable he wishes.

The cockpit consists of a chair upon which the throttle and control stick have been mounted. The stick, mounted on the right arm, is a Gemini control stick providing all three controls: yaw, pitch and roll. At the top of the stick is located one of the control buttons used in the control of the program from the pilot station. Mounted on the left arm is a throttle plate containing a small throttle and another control button. The outputs of the cockpit are fed via a wire bundle to the rear of the analog computer for processing.

A complete operating manual is contained in Appendix H.

III. SIX DEGREE OF FREEDOM AIRFRAME EQUATIONS

R.M. Howe [Refs. 2 and 3] discusses three coordinate systems - body, wind, and stability axes - and concludes that the use of wind axes for the translational equations and of body axes for the rotational equations of motion is the best choice. As can be seen from Figure 2, the body axes differ from the stability axes by the aircraft angle of attack, while the stability axes differ from the wind or flight path axes by the side slip angle.

Assuming that the three angular rates of the aircraft (P,Q,R) about the body axis are given, the angular rates about the stability axis (P_s, Q_s, R_s) can be computed (Eqn 101-103).

$$P_s = P \cos \alpha + R \sin \alpha \quad (101)$$

$$Q_s = Q \quad (102)$$

$$R_s = P \sin \alpha + Q \cos \alpha \quad (103)$$

These angular rates can then be normalized using equations 104-106.

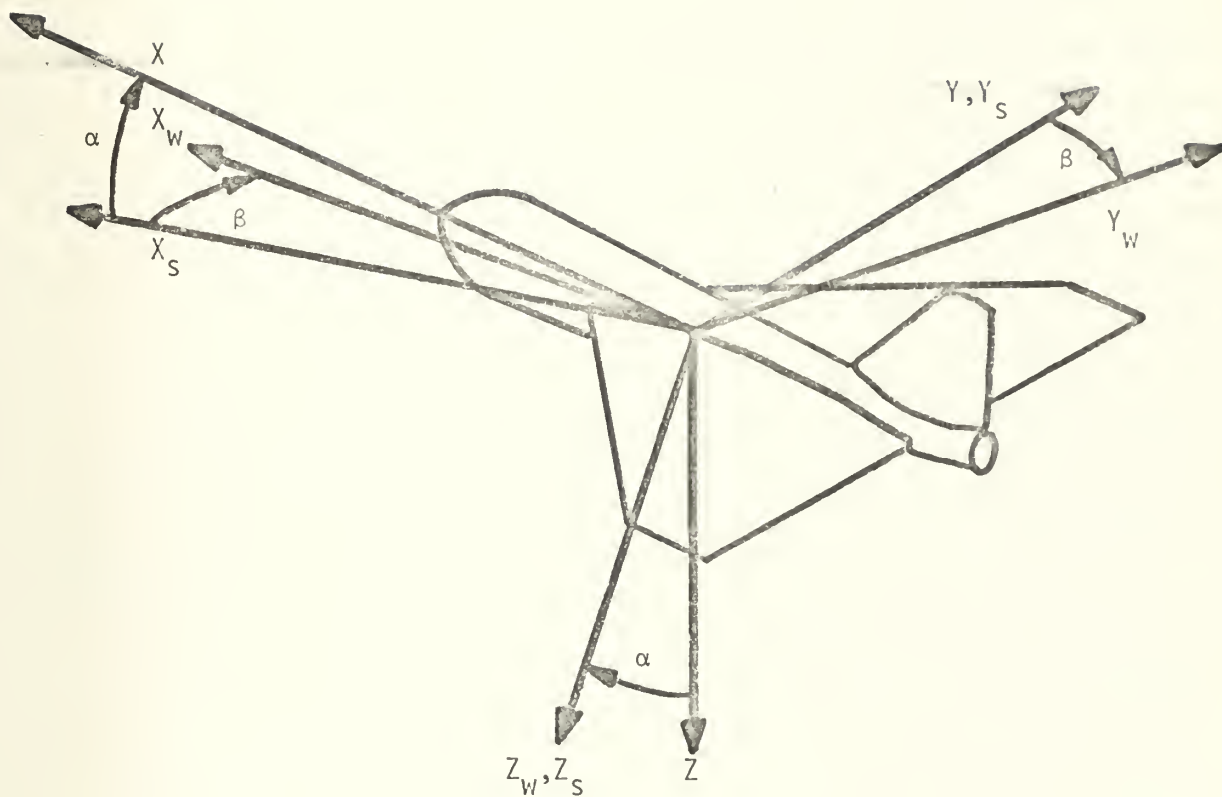
$$\bar{P}_s = \frac{P_s b}{2V} \quad (104)$$

$$\bar{Q}_s = \frac{Q_s b}{2V} \quad (105)$$

$$\bar{R}_s = \frac{R_s b}{2V} \quad (106)$$

The aerodynamic forces expressed along the stability axes can then be calculated (Eqn 107-109).

$$\frac{F_{x_{aero}}}{m} = q \left(\frac{-SC_D}{m} \right) \quad (107)$$



X, Y, Z - Body Axis
 X_S, Y_S, Z_S - Stability Axis
 X_W, Y_W, Z_W - Wind or Flight Path Axis

Figure 2. Aircraft Coordinate Axis.

$$\frac{F_{Y_{aero}}}{m} = q \left[\frac{SC_Y}{m} + \frac{\overline{SR}_S C_{Y_R}}{m} + \frac{\overline{SP}_S C_{Y_P}}{m} + \frac{SC_Y \delta r}{m} + \frac{SC_Y \delta a}{m} \right] \quad (108)$$

$$\frac{F_{Z_{aero}}}{m} = q \left[\frac{SC_L}{m} + \frac{\overline{Q}_S(-S)C_{L_Q}}{m} + \frac{\dot{\alpha}\overline{C}(-S)C_{L_{\dot{\alpha}}}}{2Vm} + \frac{\delta it(-S)C_{L_{\delta it}}}{m} \right] \quad (109)$$

The forces in the body axes are then resolved into forces in the stability axes (Eqn 110-112). Thrust and the force of gravity are included at this time. Thrust was assumed to have only an X component.

$$\frac{F_{X_S}}{m} = \left(\frac{T}{m} - g \sin \theta \right) \cos \alpha + g \cos \theta \cos \phi \sin \alpha + \frac{F_{X_{aero}}}{m} \quad (110)$$

$$\frac{F_{Y_S}}{m} = g \cos \theta \sin \phi + \frac{F_{Y_{aero}}}{m} \quad (111)$$

$$\frac{F_{Z_S}}{m} = - \left(\frac{T}{m} - g \sin \theta \right) \sin \alpha + g \cos \theta \cos \phi \cos \alpha + \frac{F_{Z_{aero}}}{m} \quad (112)$$

The forces are then resolved from the stability axes to the wind or flight path axes (Eqn 113-115).

$$\frac{F_{X_W}}{m} = \frac{F_{X_S}}{m} \cos \beta + \frac{F_{Y_S}}{m} \sin \beta \quad (113)$$

$$\frac{F_{Y_W}}{m} = \frac{-F_{X_S}}{m} \sin \beta + \frac{F_{Y_S}}{m} \cos \beta \quad (114)$$

$$\frac{F_{Z_W}}{m} = \frac{F_{Z_S}}{m} \quad (115)$$

From these equations the translational equations of motion can be determined. Solving for the derivatives yields equations 116-118.

$$\dot{V} = \frac{F_{X_W}}{m} \quad (116)$$

$$-\dot{\alpha} = \frac{-F_{Z_W}}{mV \cos \beta} + \frac{P_S \sin \beta}{\cos \beta} - Q_S \quad (117)$$

$$\dot{-\beta} = \frac{-F_{X_W}}{mV} + R_S \quad (118)$$

Further, the Euler angular rates can then be calculated (Eqn 119-121).

$$\dot{-\psi} = - \frac{(R \cos \phi + Q \sin \phi)}{\cos \theta} \quad (119)$$

$$\dot{-\theta} = - Q \cos \phi + R \sin \phi \quad (120)$$

$$\dot{-\phi} = - P + \dot{\psi} \sin \theta \quad (121)$$

Now focusing our attention on the moment equations, the three equations about the stability axes can be written as follows (Eqn 122-124).

$$\frac{L_S}{I_{xx}} = q \left[\frac{SbC_l}{I_{xx}} + \frac{\bar{P}_S SbC_{l_p}}{I_{xx}} + \frac{\bar{R}_S SbC_{l_R}}{I_{xx}} + \frac{\delta a SbC_{l_{\delta a}}}{I_{xx}} + \frac{\delta r SbC_{l_{\delta r}}}{I_{xx}} \right] \quad (122)$$

$$\frac{M_S}{I_{yy}} = q \left[\frac{S_{\dot{c}} C_m}{I_{yy}} + \frac{\bar{Q}_S S_{\dot{c}} C_{m_Q}}{I_{yy}} + \frac{\dot{\alpha} S_{\dot{c}} C_{m_{\dot{\alpha}}}}{I_{yy}} + \frac{\delta it S_{\dot{c}} C_{m_{\delta it}}}{I_{yy}} \right] \quad (123)$$

$$\frac{N_S}{I_{zz}} = q \left[\frac{SbC_n}{I_{zz}} + \frac{\bar{P}_S SbC_{n_p}}{I_{zz}} + \frac{\bar{R}_S SbC_{n_R}}{I_{zz}} + \frac{\delta a SbC_{n_{\delta a}}}{I_{zz}} + \frac{\delta r SbC_{n_{\delta r}}}{I_{zz}} \right] \quad (124)$$

These moments are then resolved into the body axes yielding

Equations 125-127.

$$\frac{L}{I_{xx}} = \frac{L_S}{I_{xx}} \cos \alpha - \frac{N_S}{I_{zz}} \sin \alpha \quad (125)$$

$$\frac{M}{I_{yy}} = \frac{M_S}{I_{yy}} \quad (126)$$

$$\frac{N}{I_{zz}} = \frac{L_S}{I_{xx}} \sin \alpha + \frac{N_S}{I_{zz}} \cos \alpha \quad (127)$$

The rotational equations of motion can then be written (Equations 128-130).

$$\dot{p} = \frac{(I_{yy} - I_{zz})}{I_{xx}} QR + \frac{I_{xz}(\dot{R} + PQ)}{I_{xx}} + \frac{L}{I_{xx}} \quad (128)$$

$$\dot{Q} = \frac{(I_{zz} - I_{xx})}{I_{yy}} RP + \frac{I_{xz} (R^2 - P^2)}{I_{yy}} + \frac{M}{I_{yy}} \quad (129)$$

$$\dot{R} = \frac{(I_{xx} - I_{yy})}{I_{zz}} PQ + \frac{I_{xz} (\dot{P} - QR)}{I_{zz}} + \frac{N}{I_{zz}} \quad (130)$$

As suggested by Howe [Ref. 2], a simplified method for computing the velocities in the inertial frame yields equations 131-133. This approach uses small angle approximations in its development.

$$\dot{S}_x = V \cos \theta \cos \psi \quad (131)$$

$$\dot{S}_y = V \cos \theta \sin \psi \quad (132)$$

$$\dot{S}_z = V(-\sin \theta + \sin \alpha \cos \theta \cos \phi) \quad (133)$$

The various derivatives that were solved for in the above equations can then be integrated yielding the state variables that were assumed to exist at the start (Eqns 134-145)

$$P = \int \dot{P} dt \quad (134)$$

$$Q = \int \dot{Q} dt \quad (135)$$

$$R = \int \dot{R} dt \quad (136)$$

$$\alpha = \int \dot{\alpha} dt \quad (137)$$

$$\beta = \int \dot{\beta} dt \quad (138)$$

$$\psi = \int \dot{\psi} dt \quad (139)$$

$$\theta = \int \dot{\theta} dt \quad (140)$$

$$\phi = \int \dot{\phi} dt \quad (141)$$

$$V = \int \dot{V} dt \quad (142)$$

$$x = \int \dot{S}_x dt \quad (143)$$

$$y = \int \dot{S}_y dt \quad (144)$$

$$z = \int \dot{S}_z dt \quad (145)$$

The equations themselves, when examined, seemingly divide themselves into two groups. One that can be solved by digital means and one that can be solved by the use of the analog computer. In fact this logical division is the one chosen for the simulator.

IV. GRAPHICS PRESENTATION

Since the primary scan during a carrier approach consists of only three things, the "meatball" or the Fresnel Lens Optical Landing System, the aircraft's angle of attack and the line-up with the runway center-line, it was decided to incorporate only these three visual cues into the display.

The angle of attack was represented by an angle of attack indexer situated in the upper right hand corner of the display. Its operation is exactly the same as the one found in the jets/turboprops operating in the Navy today. The indexer has five discrete states as shown in Figure 3.

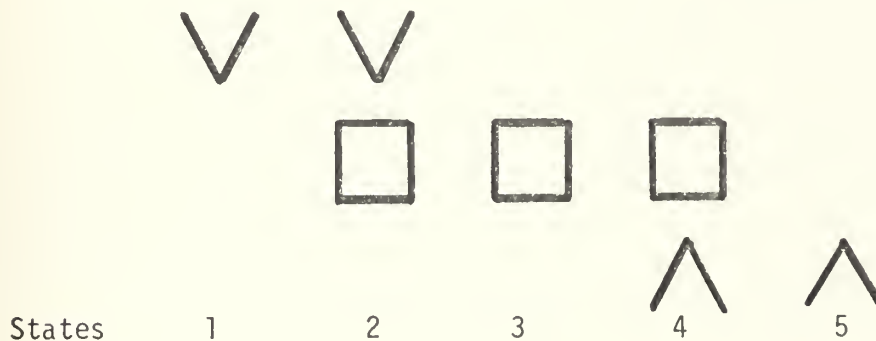


Figure 3. Angle of Attack Indexer States.

Optimum/Landing angle of attack was represented by State 3. As one increases the angle of attack of the aircraft, State 2 would appear indicating the aircraft was a "little slow" and eventually State 1 would appear indicating that the aircraft was "slow". Proceeding the other direction from State 3, that is decreasing the angle of attack, first State 4 would appear indicating the aircraft was a "little fast" and finally State 5 would appear indicating the aircraft was "fast". In

terms of degrees, assuming optimum angle of attack to be 0° , the following would exist:

| STATES | RANGE OF AOA |
|--------|---------------------------------------|
| 1 | Greater than 2.0° |
| 2 | Between 1.0° and 2.0° |
| 3 | 1.0° to -1.0° |
| 4 | Between -1.0° and -2.0° |
| 5 | Less than -2.0° |

The Fresnel Lens is represented by two fixed rectangular boxes for the datum lights and a movable square for the "meatball" as shown in Figure 4.



Figure 4. Centered Meatball.

The operation is again the same as found in the Navy systems. If the "meatball" is above the datum bars, as in Figure 5, the aircraft is above the glide slope.



Figure 5. High Meatball.

If the "meatball" is below the datum bars, as in Figure 6, the aircraft is below the glide slope.



Figure 6. Low Meatball.

The object is to keep the "meatball" centered within the datums. The "meatball" has a 1.5 degree visibility arc centered on the optimum glide slope and will disappear if this is exceeded. Also, once you fly past the lens itself the "meatball" will disappear. However, in this simulation the datums will remain visible at all times, only the "meatball" disappears.

Since the lens is affixed to the carrier/runway in real life, the size of the presentation will change. However, since the vast majority of flight cues are absent in the simulator, the size of the simulated lens will remain fixed. This presentation is placed in the upper left hand corner of the display.

The line-up cue is received from the picture of the runway itself. The picture shown is as if a movie camera were affixed to the nose (X-axis) of the aircraft. The field of view is a square with an angular limit of plus or minus 18.5 degrees in the vertical and horizontal directions. Within this window lies the horizon and the runway outline. Tic marks at 0° and plus and minus 10° of pitch are given along the left side of the window. As the aircraft maneuvers through space the runway and horizon move dynamically as if filmed by the movie camera. The complete display is shown in Figure 7.

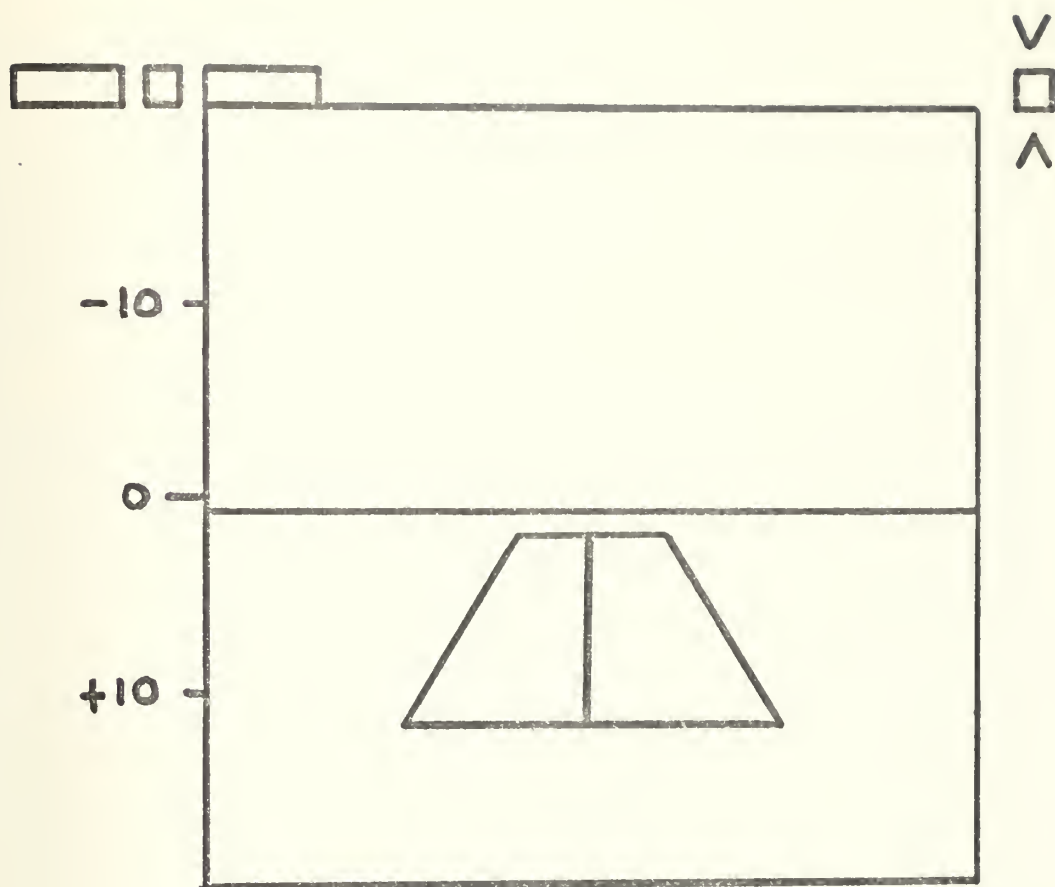


Figure 7. The Complete Graphics Display.

V. PROCESSING THE DISPLAY

The processing of the angle of attack indexer is straightforward as it is solely a function of the angle of attack of the aircraft. A simple test of the angle of attack will yield one of the five previously mentioned states.

The Fresnel Lens or "meatball" is again a simple task to process. Knowing the x-coordinate and the z-coordinate of the aircraft and the x-coordinate of the lens, the glide slope angle can be calculated.

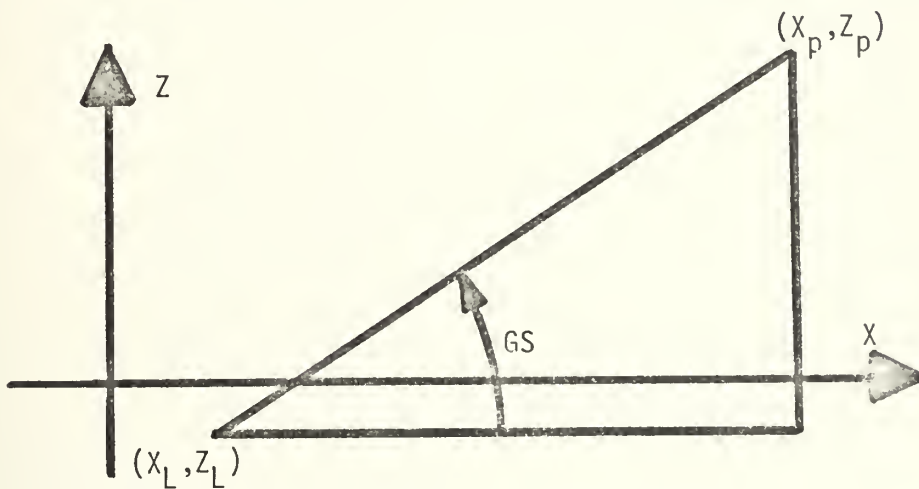


Figure 8. Glide Slope Computation.

The angle GS in Figure 8 is the glide slope angle while (x_p, z_p) and (x_L, z_L) are the coordinates of the plane and lens respectively.

$$GS = \tan^{-1}((z_p - z_L)/(x_p - x_L))$$

Angle GS is then calculated and compared to the optimum glide slope, and the "meatball" is drawn accordingly. If GS is greater than the allowable limits, or if $x_p < x_L$, the "meatball" is not displayed.

The processing of the runway is by far the most complicated. How to transform a three-dimensional object like the runway into a two-dimensional object capable of being displayed on the screen of a CRT?

The answer was found in two works, one by L.G. Roberts [Ref. 3] and the other by R.B. Desens [Ref. 4]. Roberts introduces the idea of a homogeneous coordinate system which introduces a fourth coordinate or variable scale factor. He also constructs a single transformation matrix for all points. This transformation matrix (H-Matrix) is a product of five matrices: rotation, translation, perspective, another translation and scale. Each point is post-multiplied by the H-Matrix and then the scale factor is divided out yielding the display coordinates. Desens used this to process pictures of an aircraft carrier from various positions. He also reduced the H-Matrix to a product of three individual matrices as shown in Figure 9.

$$H = \begin{bmatrix} A_1 & A_2 & A_3 & 0 \\ B_1 & B_2 & B_3 & 0 \\ C_1 & C_2 & C_3 & 0 \\ X_T & Y_T & Z_T & 1 \end{bmatrix} \begin{bmatrix} AA_1 & AA_2 & AA_3 & 0 \\ BB_1 & BB_2 & BB_3 & 0 \\ CC_1 & CC_2 & CC_3 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} 1 & -Y_0/F & -Z_0/F & -S/F \\ 0 & 1 & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & Y_0 & Z_0 & S \end{bmatrix}$$

Object Axis
Rotation
(Euler Angles)
Viewing Plane
Translation

Viewing Plane
Orientation

Perspective
Scale
Offset

Figure 9. H-Matrix

Figure 10 has the two coordinate systems, that of the earth and that of the aircraft. The viewing plane or camera is placed on the nose of the aircraft while the runway is oriented in the object or earth reference system. The first matrix is made up in part by the direction cosines of the Euler angle rotation of the object (runway). In this case the runway is fixed. The Euler angle direction cosines are given below and are based on the rotations shown in Figure 11.

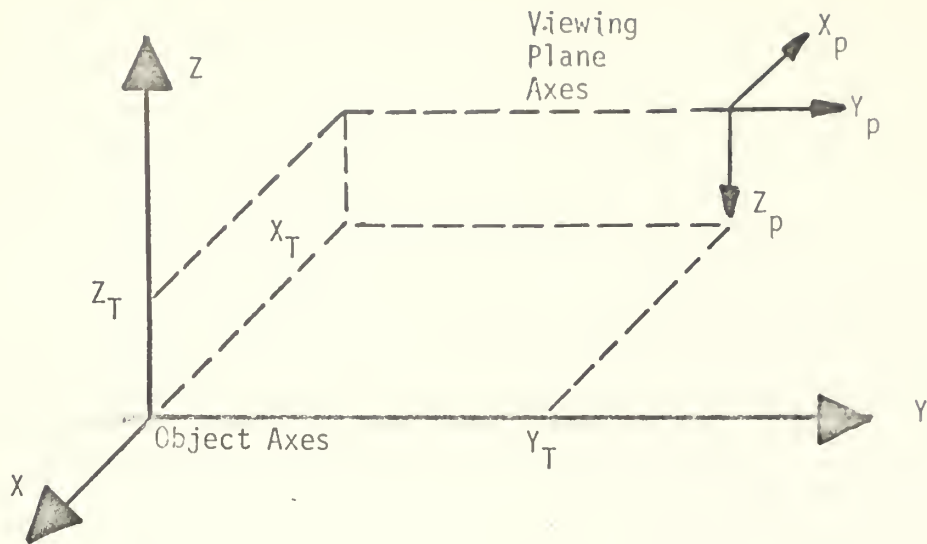


Figure 10. Graphic Coordinate System.

Euler Angle Direction Cosines

$$A_1 = \cos \beta \cos \alpha$$

$$A_2 = \cos \beta \sin \alpha$$

$$A_3 = -\sin \beta$$

$$B_1 = -\cos \gamma \sin \alpha + \sin \gamma \sin \beta \cos \alpha$$

$$B_2 = \cos \alpha \cos \gamma + \sin \gamma \sin \beta \sin \alpha$$

$$B_3 = \sin \gamma \cos \beta$$

$$C_1 = \sin \gamma \sin \alpha + \cos \gamma \sin \beta \cos \alpha$$

$$C_2 = -\sin \gamma \cos \alpha + \cos \gamma \sin \beta \sin \alpha$$

$$C_3 = \cos \beta \cos \gamma$$

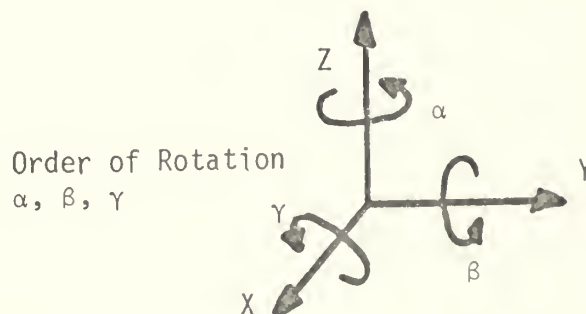


Figure 11. Euler Angle Rotation.

X_T , Y_T and Z_T are the translation distances between the two axis systems.

$$X_T = X_{\text{object}} - X_{\text{view plane}}$$

$$Y_T = Y_{\text{object}} - Y_{\text{view plane}}$$

$$Z_T = Z_{\text{object}} - Z_{\text{view plane}}$$

The second matrix is made up entirely of the viewing-plane-orientation direction cosines. The direction cosines are given below in terms of the Euler angles of the aircraft.

$$AA_1 = \cos \psi \cos \theta$$

$$AA_2 = \sin \psi \cos \phi - \cos \psi \sin \theta \sin \phi$$

$$AA_3 = \sin \psi \sin \phi + \cos \psi \sin \theta \cos \phi$$

$$BB_1 = -\cos \theta \sin \psi$$

$$BB_2 = \cos \psi \cos \phi + \sin \theta \sin \psi \sin \phi$$

$$BB_3 = \cos \psi \sin \phi - \sin \psi \sin \theta \cos \phi$$

$$CC_1 = -\sin \theta$$

$$CC_2 = -\cos \theta \sin \phi$$

$$CC_3 = \cos \theta \cos \phi$$

Order of Rotation

ψ (yaw), θ (pitch), ϕ (roll)

The third matrix consists of the offset option, Z_0 and Y_0 , which allows one to look at an offset portion of the viewing plane. This option is not used on this display. The matrix also contains the scale factor (S) and the focal length (F). The scale factor is set at 1/2 and the focal length, the distance between the viewer and the viewing plane, is set at 1.5 ft. The field of view is controlled by S and F and is equal to $\tan^{-1}(S/F)$.

A point on the object (X,Y,Z) is converted to homogeneous coordinates by the addition of another scale factor (W) yielding (X', Y', Z',W) where $X' = WX$, $Y' = WY$, $Z' = WZ$. This then is post multiplied by the

H-Matrix yielding (X'', Y'', Z'', W') . The display coordinates of the processed point can then be found by dividing by W'

$$Y''' = Y''/W'$$

$$Z''' = Z''/W'$$

The coordinate $X''' = X''/W'$ is an indicator of depth and can be used for depth cues, however, it is not used in this display. Each point of the runway is passed through the H-Matrix yielding the display coordinates of each point in turn.

Turning to the problem of the horizon and referencing Figure 12 below the following computations are presented.

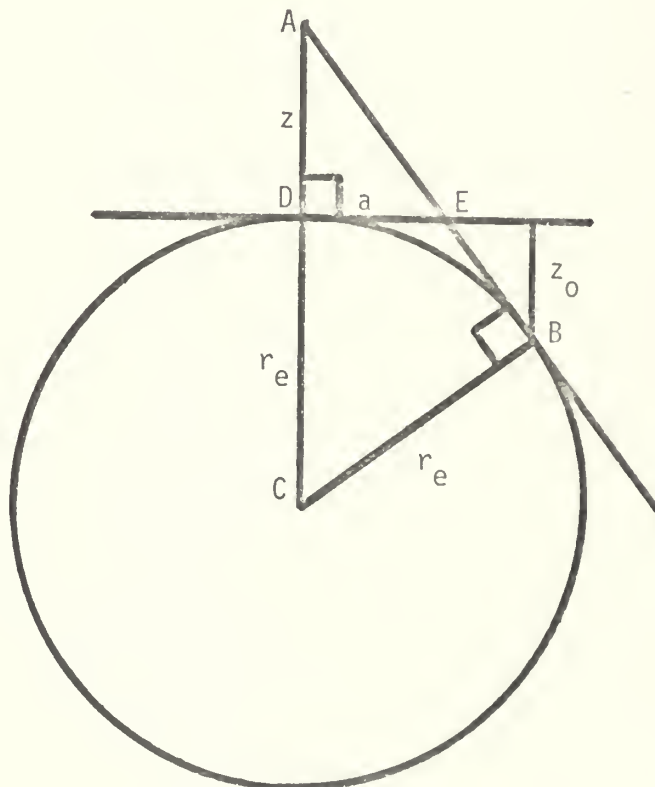


Figure 12. Horizon and Earth.

For an aircraft at point A with altitude z above the earth with radius r_e , the true horizon is at point B. This is depressed a distance z_0 from the plane DE which is tangent to the earth at point D. However,

a pseudo horizon exists at point E which always has a z coordinate of zero and visually coincides with the true horizon but has the advantage of being quicker to draw.

From Figure 12, since triangle ADE and ABC are similar this yields:

$$\frac{DE}{AD} = \frac{a}{z} = \frac{BC}{AB} = \frac{r_e}{AB}$$

$$a = \frac{R_e(z)}{AB}$$

$$(z + r_e)^2 = AB^2 + r_e^2$$

$$AB = (z^2 + 2(r_e)z)^{\frac{1}{2}}$$

$$a = \frac{r_e(z)^{\frac{1}{2}}}{(z - 2r_e)^{\frac{1}{2}}}$$

assuming $2r_e$ to be very much greater than z yields:

$$a = \frac{r_e(z)^{\frac{1}{2}}}{(2r_e)^{\frac{1}{2}}} = K(z)^{\frac{1}{2}} \quad \text{where } K = \frac{(41.8)^{\frac{1}{2}}}{2} \times 10^3$$

The depression angle of the horizon is:

$$\text{dep} = 90^\circ - \tan^{-1}(a/z) = 90^\circ - \tan^{-1}(K(z)^{\frac{1}{2}}/z)$$

Referring to Figure 13, which is a view of the window and horizon, the object is to calculate YMID, the y intercept of the horizon. The distance PITCH can be calculated knowing the pitch angle and the field view.

$$\text{PITCH} = \theta / \text{Field of View}$$

TPITCH is PITCH minus the depression angle DEPA. Simple trig yields $\cos \phi = \text{TPITCH}/\text{YMID}$, where ϕ is the roll angle of the aircraft.

$$\text{YMID} = \text{TPITCH} / \cos \phi$$

Knowing YMID and the roll angle the horizon can then be constructed. Upon the completion of the runway and the horizon, the lines are placed through a software window algorithm that will cause only the lines within the window/field of view to be displayed. This computation is done for every iteration of the problem solution.

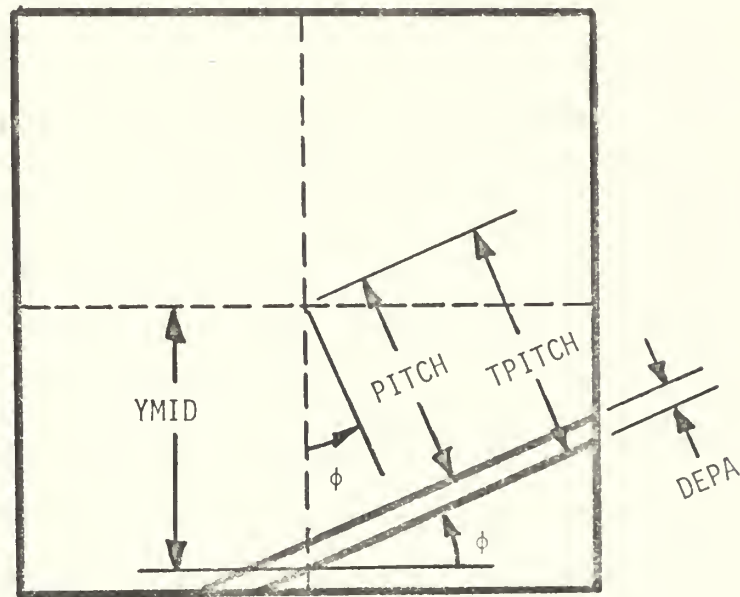


Figure 13. Calculating Horizon Intercept.

VI. THE PROGRAM

As stated in Section III, a logical division of tasks exist. To integrate the derivatives of the twelve state variables by digital algorithms takes too much computational time, therefore the logical thing to do was to D/A these variables and integrate them on a real-time basis using the analog computer. The results are then A/D'd back to the digital computer for calculation of the derivatives. This forms the computational loop.

When a real-time simulation is undertaken the time involved for the solution of the problem must be a minimum. Great pains were taken to insure that this was indeed done. The following is a tabulation of the significant time-saving steps that were involved:

1. Resolution of the angles in the digital computer using a sine table lookup.
2. Fast linear interpolation used in both the sine table lookup and the aerodynamic coefficient lookup.
3. Preprocessing of the aerodynamic data to yield usable aerodynamic coefficients.
4. General and liberal use of program constants to combine two or more arithmetic operations.
5. Use of the SQRT function vice the exponential function.
6. Multiple assignment.
7. Rewriting by the Laboratory staff of the A/D - D/a routine resulting in the SUBROUTINE ADDA.
8. Rewriting of the digital processor control program GATED to yield a faster version GATD1.

9. The use of equivalencing scalars to vector elements to reduce the indexing time within the digital computer.
10. Judicious programming and a dedicated cleaning up process of the generated code for the computational loop.

The total time for the computational loop using the above procedures was cut from an original 190 milliseconds to 55 milliseconds. This gives an approximate solution update rate and graphic frame rate of 18 samples or frames per second.

The simulator was finally flown but the dynamic response was not quite as expected. The aircraft seemed to be unstable in the Dutch Roll mode, so a yaw damper was constructed. This helped, but at times the aircraft was still unstable. Investigation into dynamic error analysis [Ref. 5] demonstrated that the computational loop time delay was causing a degradation in the damping ratio. The lowest damping ratio was in the Dutch Roll mode, hence the appearance of the instability there. The solution was to predict ahead a value to be used by the program using the known derivatives. When this prediction and update was incorporated, all instabilities were corrected.

Engine dynamic response was added in an effort to make the throttle response realistic [Ref. 6]. Also, in an attempt to increase the number of cues available to the pilot, variable frequency noise was generated in proportion to the power applied. When weighed against the results achieved, it was decided to discard the noise generator in favor of the simplicity of setup and operation.

The digital program in its entirety can be found in Appendix A, while the analog diagram can be found in Appendix B. In an effort to make the program more readable, Appendix C contains descriptors of all

the program variables used, and Appendix D contains a program flow diagram. Sample output of the program can be found in Appendix G.

VII. CONCLUSIONS

Dynamic validation of the simulator was done by comparing the various modes of response. The tabulation below shows that in fact the dynamic response of the simulator is excellent when compared with the actual aircraft, in this case the A-7.

| | Simulator | Aircraft |
|------------------------------------|------------------------------|-----------|
| 1. Dutch Roll Natural Frequency | .25 cps | .25 cps |
| 2. Short Period | 2.0 sec | 2.3 sec |
| 3. Phygoid Period | 37 sec | 38 sec |
| 4. Roll Mode | Heavily damped in both cases | |
| 5. Spiral Divergence Time Constant | 29 sec | 25-35 sec |

The simulator has now met the self-imposed requirements set forth in the Introduction. Briefly reviewing the points in the Introduction:

1. Multi-task simulator - Currently three follow-on studies are being conducted using the simulator. These include a spin simulation, investigation into stall dynamics and a study involved with a LSO work station.
2. Ability to change the aircraft being simulated - Demonstrations have been conducted with the "standard" Navy runway and the carrier runway dimensions as well as linearized and non-linearized aerodynamic data. Time involved to change, in each case, was approximately one minute.
3. The use of interactive graphics for the display - Very good results were achieved using the inside-out display. Results show that there is a learning curve as with any simulator but

sufficient visual cues are provided to enable consistent landings by experienced pilots.

4. Simplicity of setup and operation - The number of dials or buttons have been kept to a minimum; as a result the system can be up and operating within five minutes. As for the operation, the simulator has been flown by all manner of people with little or no explanation needed.

Possible areas of follow-on study might include the following:

1. The study of Heads Up Displays (HUD's), since only the graphic presentation need be changed.
2. Autopilot/Gust Alleviators/Stability Augmentor systems that can be modeled on an analog board can be incorporated, as approximately one-half the board is left unused for this purpose.
3. Force-stick analyzation with a realistic tracking problem.
4. Re-design of the Optical Landing System to reduce the false motion cues that currently exist in the present system.

APPENDIX A - THE DIGITAL PROGRAM

This appendix includes listings of the main program, written in FORTRAN, and the SUBROUTINE ADDA, the A/D - D/A subprogram. The subroutine is written in METASYMBOL, the assembly language for the XDS - 9300 and was prepared by the computer laboratory staff.


```

X(P5(1,1),PP51),(P5(1,2),PP52),(P5(1,3),PP53),(P5(1,4),PP54),
X(P6(1,1),PP61),(P6(1,2),PP62),(P6(1,3),PP63),(P6(1,4),PP64),
X(CA(1),CCA1),(CA(2),CCA2),(SA(1),SSA1),(SA(2),SSA2),
X(CA(3),CCA3),(CA(4),CCA4),(CA(5),CCA5),(SA(3),SSA3),
X(SA(4),SSA4),(SA(5),SSA5),(AD(7),QSQ),(H1(4,1),SX),(H1(4,2),SY),
X(H1(4,3),SZ),(AD(1),A(1)),(AD(2),A(2)),(AD(3),A(3)),(AD(4),A(4)),
X(AD(5),A(5)),(AD(6),P),(AD(8),R),(AD(9),TM),(AD(10),DIT)
X,(AD(11),DA),(AD(12),DR),(AD(13),V),(AD(14),QUE),(AD(15),SXN),
X(AD(16),SYN),(AD(17),S7N),(AA(1),VDET),(AA(2),ADGTN(1)),
X(AA(3),ADETN(2)),(AA(4),ADETN(3)),(AA(5),ADETN(4)),
X(AA(6),ADETN(5)),(AA(7),ALI),(AA(8),SDGT(1)),(AA(9),SDGT(2)),
X (AA(10),SDGT(3)),(AA(11),AMI),(AA(12),ANI),(SFA(1),SF8),
X(SFA(2),SF9),(AD(18),PCGTN),(AD(19),CDGTN),(AD(20),RDGTN)
DATA AD/12*0.0,6,36,6*0.0,ND/12,NAD/20,G/32,2,H1(1,2),
XH1(1,3),H1(1,4),H1(2,1),H1(2,3),H1(2,4),H1(3,1),H1(3,2),H1(3,4),
XH2(2,4),H2(3,4),H2(4,1),H2(4,2),H2(4,3),H3(3,2),H3(2,3),Z9,Y8,
XH3(2,4),H3(3,4),H2(1,4)/21*0.0,H1(1,1),H1(2,2),H1(3,3),H1(4,4),
XH2(4,4),H3(2,2),H3(3,3)/7*1.0/SFAC/1.5,F1.5,ADGT8/5*0.0/,
YVDET8/0.0,DEGT/-40,-30,-20,-10,0,0,10,20,30,40,/,
XDEGA/-25,-20,-15,-10,-5,0,0,5,10,15,20,25,30,35,/,
X40,45,/,K/5,9,10,14,15,19,20,24/,KP8T/0,24,1,25,2,26,3,27,4,30,
X5,31,6,32,7,33,10,34,11,35,12,36,13,37,14,40,15,41,16,42,17,43,
X20,44,21,45,22,46,23,50/
*****
*
*
*
*
*****
*
*
*
*
*****
51 FORMAT(3F10.0)
100 FORMAT(I1)
102 FORMAT(4F10.0)
103 FORMAT(I2,2X,I1,5X,7F10.7/8F10.7)
104 FORMAT(I2,3X,7F10.7/8F10.7)
105 FORMAT('O',I2,2X,I1,5X,7(F10.7,2X)/',8(F10.7,2X))
106 FORMAT('O',I2,2X,7(F10.7,2X)/',8(F10.7,2X))

```



```

107 FORMAT('1',' ')
108 FORMAT(8F10.0)
110 FORMAT(6F10.2)
111 FORMAT(8F10.2/8F10.2/3F10.2)
120 FORMAT('0',20X,'A000 INDICATES -PD0T',F5.2,4X,
X'A001 INDICATES +P',F5.2,7X,
X'A002 INDICATES -QD9T',F5.2,/,21X,
X'A003 INDICATES +Q',F5.2,7X,
X'A006 INDICATES -RD9T',F5.2,4X,
X'A007 INDICATES +R',F5.2,/,21X,
X'A015 INDICATES +T/RMASS',F3.0,3X,
X'A017 INDICATES -SX',F6.0,5X,
X'A051 INDICATES -SY',F6.0,/,21X,
X'A023 INDICATES -SZ',F6.0,5X,
X'A024 INDICATES DIT',F3.0,8X,
X'A025 INDICATES THETA',F3.0,/,21X,
X'A026 INDICATES DA',F3.0,9X,
X'A031 INDICATES PETA',F3.0,7X,
X'A033 INDICATES PHI',F3.0,/,21X,
X'A034 INDICATES QUE',F6.2,5X,
X'A035 INDICATES PSI',F3.0,8X,
X'A036 INDICATES VEL',F4.0,/,21X,
X'A041 INDICATES DR',F3.0,5X,
X'A045 INDICATES ALPHA',F3.0,/)
121 FORMAT('0',20X,'T420 INDICATES VD9T',F3.0,7X,
X'T421 INDICATES -ALPHA09T',F3.1,2X,
X'T422 INDICATES -BETA09T',F3.1,/,21X,
X'T423 INDICATES -PSID9T',F3.1,4X,
X'T424 INDICATES -THETA09T',F3.1,2X,
X'T425 INDICATES -PHID9T',F3.1,/,21X,
X'T426 INDICATES ALI',F4.2,7X,
X'T427 INDICATES SX09T',F4.0,5X,
X'T430 INDICATES SY09T',F4.0,/,21X,
X'T431 INDICATES SZ09T',F4.0,5X,
X'T432 INDICATES AVI',F4.2,7X,

```



```

X'T433 INDICATES ANI/','F4.2)
122 FORMAT(' ','20X','THE OUTPUTS OF THE AMPLIFIERS ARE REPRESENTATIVE OF
  XF THE FOLLOWING SCALED VARIABLES:'))
123 FORMAT(' ','20X','THE D/A TRUNKS REPRESENT THE FOLLOWING SCALED VARI
  XABLES:'))
130 FORMAT('THE FOLLOWING PROGRAM OPTIONS  '))
131 FORMAT('ARE OFFERED AT THIS TIME:  '))
132 FORMAT('1. TO STOP PROGRAM - TYPE A 1 FOLLOWED BY A '))
133 FORMAT('DECIMAL POINT AND A RETURN.  '))
134 FORMAT('2. TO FLY AGAIN WITH SAME PROGRAM PARAMETERS -  '))
135 FORMAT('TYPE A 2 FOLLOWED BY A DECIMAL POINT AND  '))
136 FORMAT('A RETURN.  '))
137 FORMAT('3. TO CHANGE ANY PROGRAM PARAMETER - LEAD AND  '))
138 FORMAT('READY CARD READER WITH COMPLETE DATA DECK -  '))
139 FORMAT('TYPE A 3 FOLLOWED BY A DECIMAL POINT AND A  '))
140 FORMAT('RETURN.  '))
141 FORMAT('TYPE YOUR SELECTION HERE  '))
142 FORMAT('USE A DECIMAL POINT  '))
143 FORMAT('TO FLY AGAIN PUNCH THE BUTTON  '))
144 FORMAT('INPUT ERROR TRY AGAIN  '))
145 FORMAT('ON THE CENTRAL STICK.  '))
146 FORMAT('TO RECEIVE PROGRAM OPTIONS  '))
147 FORMAT('PUNCH THE BUTTON ON THE  '))
148 FORMAT('THROTTLE PLATE.  '))
301 FORMAT('CARRIER APPROACH  '))
302 FORMAT('LANDING SIMULATOR  '))
303 FORMAT('(CALS)  '))
304 FORMAT('RY  '))
305 FORMAT('LCDR J.H. KAHR'S  '))
306 FORMAT('AND  '))
307 FORMAT('LTJG M.H. REDLIN  '))
308 FORMAT('ASST PROF AER9 ENG  '))
309 FORMAT('NAVAL POSTGRADUATE SCHOOL  '))
310 FORMAT('MARCH 1972  '))
311 FORMAT('INSTRUCTIONS  '))

```



```

X41X,'SF14' = ',F10.3,20X,'SZO' = ',F10.3,/,
X41X,'SF15' = ',F10.3,20X,'VO' = ',F10.3,/,
X41X,'SF16' = ',F10.3,20X,'A10' = ',F10.3,/,
X41X,'SF17' = ',F10.3,20X,'DITO' = ',F10.3,/,
X41X,'SF18' = ',F10.3,20X,'RH9' = ',F10.5,/,
X41X,'SF19' = ',F10.3,20X,'WIND' = ',F10.3,/,
X41X,'SF20' = ',F10.3,/,
X41X,'SF21' = ',F10.3,20X,'W' = ',F10.3,/,
X41X,'SF22' = ',F10.3,20X,'B' = ',F10.3,/,
X41X,'SF23' = ',F10.3,20X,'CB' = ',F10.3,/,
X41X,'SF24' = ',F10.3,20X,'S' = ',F10.3,/,
X41X,'SF25' = ',F10.3,20X,'R1XX' = ',F10.3,/,
X41X,'SF26' = ',F10.3,20X,'R1YY' = ',F10.3,/,
X41X,'SF27' = ',F10.3,20X,'R1ZZ' = ',F10.3,/,
X41X,'SF28' = ',F10.3,20X,'R1XZ' = ',F10.3,/,
X41X,'SF29' = ',F10.3,20X,'T' = ',F10.3,/,
X41X,'ABALDG' = ',F8.3,20X,'SZF' = ',F10.3)
790 FORMAT(' ',58X,'RUNWAY CONSTANTS')
791 FORMAT('O',50X,'POINT',7X,'X',2X,'Y',8X,'Z',,,,
X53X,'1',4X,3(F7.1,2X),,,,53X,'2',4X,3(F7.1,2X),,,,
X53X,'3',4X,3(F7.1,2X),,,,53X,'4',4X,3(F7.1,2X),,,,
X53X,'5',4X,3(F7.1,2X),,,,53X,'6',4X,3(F7.1,2X),,,,
792 FORMAT(' ',58X,'XIR' = ',F9.3,/,59X,'HMR' = ',F9.3,/,
X59X,'GSS' = ',F9.3,/,59X,'RAMP' = ',F9.3,/,
X59X,'W1' = ',F9.3,/,59X,'W2' = ',F9.3,/,
X59X,'W3' = ',F9.3,/,59X,'W4' = ',F9.3)
901 FORMAT('LANDING RESULTS ')
902 FORMAT('YOU HAVE CRASHED ')
903 FORMAT('ROLTER ROLTER ')
904 FORMAT('YOU HAVE MISSED THE SHIP ')
905 FORMAT('ARRESTED LANDING ')
906 FORMAT('WIRE NUMBER ',I1,' ')
907 FORMAT('SINK RATE = ',F7.2,' FT/SEC ')
908 FORMAT('CAUTION - PLOW TIRE ')
909 FORMAT('5.1, FEET LEFT OF CENTERLINE ')

```



```

970 FORMAT('LINE-UP ')
971 FORMAT(F5.1,' FEET RIGHT OF CENTERLINE ')
972 FORMAT('ON CENTERLINE ')
973 FORMAT('AIRSPEED AT TOUCHDOWN ')
974 FORMAT('FAST ')
975 FORMAT('SLOW ')
976 FORMAT('IGN SPEED ')
977 FORMAT('LITTLE FAST ')
978 FORMAT('LITTLE SLOW ')
8001 FORMAT(' ',40X,'PBT('',11,'') = ',F6.5,20X,'PBT('',12,'') = ',F6.5)
8002 FORMAT(' ',40X,'PBT('',12,'') = ',F6.5,20X,'PBT('',12,'') = ',F6.5)
9000 FORMAT(' ',40X,'PBT SETTINGS',//)
*****
*
*
*
*
THE TITLE
*****
8003 OUTPUT(101)'INPUT AGT NUMBER'
READ(101,100)IDEV
IF((IDEV.NE.1).AND.(IDEV.NE.2)) GO TO 8003
CALL CGINIT(IDEV,IDIR,3,IER)
CALL DTINIT(IDEV,ITDIR,20,IER)
ENC9DE(20,301,ITEX1)
ENC9DE(20,302,ITEX2)
ENC9DE(8,303,ITEX3)
ENC9DE(4,304,ITEX4)
ENC9DE(16,305,ITEX5)
ENC9DE(4,306,ITEX6)
ENC9DE(20,307,ITEX7)
ENC9DE(20,308,ITEX8)
ENC9DE(28,309,ITEX9)
ENC9DE(16,310,ITEX10)
CALL TEXT4(IDEV,ITEX1,5,2,24,3,3,IER)
CALL TEXT9(IDEV,ITEX2,5,7,22,3,3,IER)
CALL TEXT6(IDEV,ITEX3,2,10,39,3,3,IER)

```



```

CALL TEXT0(IDEV, ITEX4,1,16,46,2,3,IER)
CALL TEXT0(IDEV, ITEX5,4,19,25,3,3,IER)
CALL TEXT0(IDEV, ITEX6,1,22,45,2,3,IER)
CALL TEXT0(IDEV, ITEX7,5,25,24,3,3,IER)
CALL TEXT0(IDEV, ITEX8,5,28,30,2,3,IER)
CALL TEXT0(IDEV, ITEX9,7,34,23,2,3,IER)
CALL TEXT0(IDEV, ITEX10,3,37,38,2,3,IER)

```

READ RUNWAY DATA

```

READ(5,102)(P1(1,J),J=1,4)
READ(5,102)(P2(1,J),J=1,4)
READ(5,102)(P3(1,J),J=1,4)
READ(5,102)(P4(1,J),J=1,4)
READ(5,102)(P5(1,J),J=1,4)
READ(5,102)(P6(1,J),J=1,4)
READ(5,51) GSB,XWIR,WIND

```

ESTABLISH PROGRAM CONSTANTS

```

CEN1=57.29577
CEN2=.2/.75
CEN3=SQRT(41.8)*1000.0/2.0
CEN4=SIN(30.0/CEN1)
CEN5=COS(30.0/CEN1)
CEN6=CEN3/CEN5
IDE(1)=IDEAD(0,10)
HWR=115.0*SIN(GSB/CEN1)/CEN5(GSB/CEN1)
H3(1,2)=-Y0/F
H3(1,3)=-Z0/F
H3(1,4)=-SPACTR/F

```



```

H3(4,2)=Y9
H3(4,3)=Z9
H3(4,4)=SFACR
DEGMAX=C6N1*ATAN(ABS(SFACR/F))
RAMP=PP41
TAU=.056*1.5

```

BUILD FIXED PORTION OF GRAPHICS

```

ISQ(1)=IHEAD(0,10)
ISQ(2)=IPACK(1.0,1.0,0)
ISQ(3)=IPACK(1.0,-1.0,1)
ISQ(4)=IPACK(-1.0,-1.0,1)
ISQ(5)=IPACK(-1.0,1.0,1)
ISQ(6)=IPACK(1.0,1.0,1)
ISQ(7)=IPACK(-1.0,1.0,0)
ISQ(8)=IPACK(-1.0,1.04,1)
ISQ(9)=IPACK(-0.8,1.04,1)
ISQ(10)=IPACK(-0.8,1.0,1)
ISQ(11)=IPACK(-1.2,1.0,0)
ISQ(12)=IPACK(-1.4,1.0,1)
ISQ(13)=IPACK(-1.4,1.04,1)
ISQ(14)=IPACK(-1.2,1.04,1)
ISQ(15)=IPACK(-1.2,1.0,1)
ISQ(16)=IPACK(-1.2,0.0,0)
ISQ(17)=IPACK(-1.0,0.0,1)
ISQ(18)=IPACK(1.0,0.0,0)
ISQ(19)=IPACK(1.2,0.0,1)
ISQ(20)=IPACK(-1.1,1.0,0/18.5),0)
ISQ(21)=IPACK(-1.0,1.0,0/18.5),1)
ISQ(22)=IPACK(1.0,1.0,0/18.5),0)
ISQ(23)=IPACK(1.1,1.0,0/18.5),1)
ISQ(24)=IPACK(-1.1,(-1.0,0/18.5),0)

```



```

ISQ(25)=IPACK(-1.0,(-10.0/18.5),1)
ISQ(26)=IPACK(1.0,(-10.0/18.5),0)
ISQ(27)=IPACK(1.1,(-10.0/18.5),1)
ISQ(28)=IPACK(-1.12,.52,0)
ISQ(29)=IPACK(-1.12,.56,1)
ISQ(30)=IPACK(-1.16,.56,1)
ISQ(31)=IPACK(-1.16,.52,1)
ISQ(32)=IPACK(-1.12,.52,1)
ISQ(33)=IPACK(-1.2,.52,0)
ISQ(34)=IPACK(-1.2,.56,1)
ISQ(35)=IPACK(-1.25,-.52,0)
ISQ(36)=IPACK(-1.25,-.56,1)
ISQ(37)=IPACK(-1.24,.54,0)
ISQ(38)=IPACK(-1.26,.54,1)
ISQ(39)=IPACK(-1.24,-.04,0)
ISQ(40)=IPACK(-1.24,.04,1)
ISQ(41)=IPACK(-1.32,.04,1)
ISQ(42)=IPACK(-1.32,-.04,1)
ISQ(43)=IPACK(-1.24,-.04,1)
ISQ(44)=IPACK(-1.12,-.52,0)
ISQ(45)=IPACK(-1.12,-.56,1)
ISQ(46)=IPACK(-1.16,-.56,1)
ISQ(47)=IPACK(-1.16,-.52,1)
ISQ(48)=IPACK(-1.12,-.52,1)
ISQ(49)=IPACK(-1.2,-.52,0)
ISQ(50)=IPACK(-1.2,-.56,1)
ISQ(51)=IPACK(-1.24,-.54,0)
ISQ(52)=IPACK(-1.26,-.54,1)
IFAST(1)=IPACK(1.04,0.5,0)
IFAST(2)=IPACK(1.12,0.58,1)
IFAST(3)=IPACK(1.2,0.8,1)
IDEN(1)=IPACK(1.08,0.96,0)
IDEN(2)=IPACK(1.08,1.04,1)
IDEN(3)=IPACK(1.16,1.04,1)
IDEN(4)=IPACK(1.16,0.96,1)

```



```

ID3N(5)=IPACK(1.08,0.96,1)
ISL0(1)=IPACK(1.04,1.2,0)
ISL0(2)=IPACK(1.12,1.12,1)
ISL0(3)=IPACK(1.2,1.2,1)
*****
*
*      READ SCALE FACTORS AND FIXED AIRCRAFT DATA
*
*****
READ(5,111) SF1,SF2,SF3,SF4,SF5,SF6,SF8,SF9,SF10,SF11,SF12,SF13,
1SF14,SF15,SF16,SF17,SF18,SF19,SF30
READ(5,110) SX0,SZ0,V0,A10,DITO,RH0
READ(5,108) W,B,CR,S,R1XX,R1YY,R1ZZ,R1XZ
READ(5,51) T,AGALDG,SZF
AGAF=AGALDG-2.0
AGALF=AGALDG-1.0
AGALS=AGALDG+1.0
AGAS=AGALDG+2.0
PMAS=X/G
ISF7=T/(RMAS*10.)+1.0
SF7=ISF7*10
SF20=SF1*SF1/(2.*SF19)
SF21=SF6/SF4
SF22=SF1/SF4
SF23=SF1/SF5
SF24=SF1/SF6
SF25=SF4/SF5
SF26=SF5/SF6
SF27=SF4*SF4
SF28=SF5*SF5
SF29=SF6*SF6
SF31=SF7/(SF1*SF5)
SF32=SF7/(SF1*SF6)
SF33=SF1/SF2
SF34=SF1/SF3

```


WRITE(6,107)
WRITE(6,780)

721 CONTINUE

*
*
*
*

COMPUTE USABLE AIRCRAFT COEFFICIENTS

D9 5001 IB=1,9
D9 5002 IA=1,15
COEFAB(1,IA,IB)=S*B*COEFAB(1,IA,IB)/R1XX*SF20/SF27
COEFAB(2,IA,IB)=S*CB*COEFAB(2,IA,IB)/R1YY*SF20/SF28
COEFAB(3,IA,IB)=S*B*COEFAB(3,IA,IB)/R1ZZ*SF20/SF29
COEFAB(4,IA,IB)=S*COEFAB(4,IA,IB)/RMASS*SF20/SF7
5002 CONTINUE
5001 CONTINUE
D9 5003 IA=1,15
COEFA(5,IA)=S*COEFA(5,IA)/RMASS*SF20/SF7
COEFA(6,IA)=S*COEFA(6,IA)/RMASS*SF20/SF7
COEFA(7,IA)=S*COEFA(7,IA)/RMASS*SF16*SF20/SF7
COEFA(8,IA)=S*CB*COEFA(8,IA)/R1YY*SF16*SF20/SF28
COEFA(9,IA)=S*COEFA(9,IA)/RMASS*SF18*SF20/SF7
COEFA(10,IA)=S*B*COEFA(10,IA)/R1XX*SF18*SF20/SF27
COEFA(11,IA)=S*B*COEFA(11,IA)/R1ZZ*SF18*SF20/SF29
COEFA(12,IA)=S*COEFA(12,IA)/RMASS*SF17*SF20/SF7
COEFA(13,IA)=S*B*COEFA(13,IA)/R1XX*SF17*SF20/SF27
COEFA(14,IA)=S*B*COEFA(14,IA)/R1ZZ*SF17*SF20/SF29
COEFA(15,IA)=S*COEFA(15,IA)/RMASS*SF20/(SF22*SF7)
COEFA(16,IA)=S*B*COEFA(16,IA)/R1XX*SF20/(SF22*SF27)
COEFA(17,IA)=S*B*COEFA(17,IA)/R1ZZ*SF20/(SF22*SF29)
COEFA(18,IA)=S*COEFA(18,IA)/RMASS*SF20/(SF24*SF7)
COEFA(19,IA)=S*B*COEFA(19,IA)/R1XX*SF20/(SF24*SF27)
COEFA(20,IA)=S*B*COEFA(20,IA)/R1ZZ*SF20/(SF24*SF29)
COEFA(21,IA)=S*COEFA(21,IA)/RMASS*SF20/(SF23*SF7)
COEFA(22,IA)=S*CB*COEFA(22,IA)/R1YY*SF20/(SF23*SF28)


```

C0EFA(23,IA)=-S*C0EFA(23,IA)/RMASS*SF20/(SF23*SF7)
C0EFA(24,IA)=S*CB*C0EFA(24,IA)/RIYY*SF20/(SF23*SF28)
5003 CONTINUE
IF(TEST(7).GT.0) GO TO 751
DO 750 I=1,4
WRITE(6,761)
WRITE(6,700)I
WRITE(6,701)(DEGB(J),J=1,9)
WRITE(6,702)
DO 749 IA=1,15
WRITE(6,703)DEGA(IA),(C0EFAB(I,IA,IB),IB=1,9)
749 CONTINUE
WRITE(6,107)
WRITE(6,780)
750 CONTINUE
DO 751 I=1,7,2
IPLS=I+1
WRITE(6,763)
WRITE(6,704)
WRITE(6,705)
WRITE(6,706)(J,J=KK(I),KK(IPLS))
DO 752 IA=1,15
WRITE(6,707)DEGA(IA),(C0EFA(J,IA),J=KK(I),KK(IPLS))
752 CONTINUE
WRITE(6,107)
WRITE(6,780)
751 CONTINUE
CALL SETLINES(1,RIXZ,2,RIYY-RIZZ,3,RIZZ-RIXX,4,RIXX-RIYY)
*****
*
*
*
*****
SETPAT ROUTINE
*****
*
*
*
*****
PAT(0)=SF5*ABS(RIXZ)/RIXX/SF4
PAT(1)=SF5*SF6/(10.*SF4)*ABS(RIYY-RIZZ)/RIXX/SF4

```


P0T(2)=SF4/10.
 P0T(3)=SF4*SF4/SF5*ABS(RIXZ)/RIYY/SF5
 P0T(4)=SF4*SF6/(10.*SF5)*ABS(RIZZ-RIXX)/RIYY/SF5
 P0T(5)=SF5/10.
 P0T(6)=SF5*ABS(RIXZ)/RIZZ/SF6
 P0T(7)=SF4*SF5/(10.*SF6)*ABS(RIXX-RIYY)/RIZZ/SF6
 P0T(10)=SF6/10.
 P0T(11)=.1*SF4/(SF5*SF6)*SF4
 P0T(12)=.1*SF6/(SF4*SF5)*SF6
 P0T(13)=.3270
 P0T(14)=T/RMASS/SF7/10./0.3166
 P9T(15)=.0260
 P0T(16)=ABS(SX0)/SF13
 P0T(17)=.5000
 P0T(20)=ABS(SZ0)/SF15
 P0T(21)=SF1/SF13
 P0T(22)=SF2/SF14
 P0T(23)=SF3/SF15
 P0T(24)=.1*180./3.1416*SF5/SF11
 P0T(25)=.1*180./3.1416*SF5/SF8
 P0T(26)=.1*180./3.1416*SF6/SF9
 P0T(27)=.1*180./3.1416*SF4/SF12
 P0T(30)=.1*180./3.1416*SF6/SF10
 P0T(31)=SF7/SF1
 P0T(32)=V0/SF1
 P0T(33)=RH9*SF19
 P0T(34)=.1/.5730
 P0T(35)=.1/.5435
 P0T(36)=.0016
 P0T(37)=.1/.4335
 P0T(40)=.0962
 P0T(41)=.2800
 P0T(42)=A10/SF8
 P0T(43)=.01*SF6*180./3.14159*SF30/SF18
 P9T(44)=ABS(DIT0)/SF16


```

POT(45)=.1*SF6*SF6/(SF4*SF4)
POT(46)=WIND*6000./3600./SF13
POT(50)=SF/SF15
IF(TEST(7).GT.0) G9 T9 12
WRITE(6,9000)
DO 777 I=1,15,2
  IPLS=I+1
  WRITE(6,8001)KPOT(I),POT(KPOT(I)),KPOT(IPLS),POT(KPOT(IPLS))
777 CONTINUE
DO 778 I=17,39,2
  IPLS=I+1
  WRITE(6,8002)KPOT(I),POT(KPOT(I)),KPOT(IPLS),POT(KPOT(IPLS))
778 CONTINUE
  WRITE(6,107)
  WRITE(6,780)
  WRITE(6,122)
  WRITE(6,120)SF27,SF4,SF28,SF5,SF29,SF6,SF7,SF13,SF14,SF15,SF16,
1SF11,SF17,SF9,SF12,SF20,SF10,SF1,SF18,SF8
  WRITE(6,123)
  WRITE(6,121)SF7,SF5,SF6,SF5,SF4,SF27,SF1,SF2,SF3,SF28,SF29
  WRITE(6,107)
12 CALL POTSET
  CALL SETPOT (4HPC00,P9T(0),4HP001,P9T(1),4HPC02,P9T(2),
14HP003,P9T(3),4HP004,P9T(4),4HP005,P9T(5),4HP006,P9T(6),
24HP007,P9T(7),4HP010,P9T(10),4HP011,P9T(11),4HP012,P9T(12),
34HP013,P9T(13),4HP014,P9T(14),4HP015,P9T(15),4HP016,P9T(16),
44HP017,P9T(17),4HP020,P9T(20),4HP021,P9T(21),4HP022,P9T(22),
54HP023,P9T(23),4HP024,P9T(24),4HP025,P9T(25),4HP026,P9T(26),
64HP027,P9T(27),4HP030,P9T(30),4HP031,P9T(31),4HP032,P9T(32),
74HP033,P9T(33),4HP034,P9T(34),4HP035,P9T(35),4HP036,P9T(36),
84HP037,P9T(37),4HP040,P9T(40),4HP041,P9T(41),4HP042,P9T(42),
94HP043,P9T(43),4HP044,P9T(44),4HP045,P9T(45),4HP046,P9T(46),
X4HP050,P9T(50))
1001 CALL SETLINES(5,-1.0,6,+1.0)
*****

```



```

* * *
* * *
* * *
* * *

```

THE INSTRUCTIONS

```

*****
CALL DTINIT(IDEV,ITDIR,20,IER)
ENCODE(16,311,ITEX11)
ENCODE(48,312,ITEX12)
ENCODE(32,313,ITEX13)
ENCODE(48,314,ITEX14)
ENCODE(48,315,ITEX15)
ENCODE(16,316,ITEX16)
ENCODE(44,317,ITEX17)
ENCODE(16,318,ITEX18)
ENCODE(48,319,ITEX19)
ENCODE(24,320,ITEX20)
CALL TEXT0(IDEV,ITEX11,4,1,30,3,3,IER)
CALL TEXT0(IDEV,ITEX12,12,7,1,2,3,IER)
CALL TEXT0(IDEV,ITEX13,8,10,1,2,3,IER)
CALL TEXT0(IDEV,ITEX14,12,16,1,2,3,IER)
CALL TEXT9(IDEV,ITEX15,12,19,1,2,3,IER)
CALL TEXT0(IDEV,ITEX16,4,22,1,2,3,IER)
CALL TEXT0(IDEV,ITEX17,11,28,1,2,3,IER)
CALL TEXT0(IDEV,ITEX18,4,31,1,2,3,IER)
CALL TEXT0(IDEV,ITEX19,12,37,1,2,3,IER)
CALL TEXT0(IDEV,ITEX20,6,40,1,2,3,IER)

```

ND=0

```

CALL RESET (1000)
900 IF (TEST(2).GT.0) G9 T6 900
CALL SETLINES(5,+1,0,6,-1,C)
805 IF (TEST(2).LT.0) G9 T9 805
CALL DTINIT(IDEV,ITDIR,20,IER)
CALL DCINIT(IDEV,IDIR,3,IER)
CALL GRAPH9(IDEV,ISG,52,1,IER)

```

```

*****
* *

```



```
* * THE LOOP * *
** **
** **
** **
1000 IF (TEST(3)*GT*.0) GO TO 950
      CALL COMPUTE
      CALL SETLINES(6,+1.0)
** **
** **
** **
** ** A/D - D/A ** **
** **
** **
950 CALL ADDA(AD,NAD,AA,NDA)
** **
** **
** ** PREDICTOR AND UPDATE ** **
** **
** **
** **
A(1)=A(1)+TAU*ADGT9(1)*SF35
A(2)=A(2)+TAU*ADGT9(2)*SF36
A(3)=A(3)+TAU*ADGT9(3)*SF37
A(4)=A(4)+TAU*ADGT9(4)*SF38
A(5)=A(5)+TAU*ADGT9(5)*SF39
V=V+TAC*VDGT9*SF40
P=P-TAU*PDGTN*SF4
G=G-TAU*GDGTN*SF5
R=R-TAU*RDGTN*SF6
DO 3400 I=1,5
  ADGT9(I)=-ADGTN(I)
3400 CONTINUE
      VDGT9=VDGT
** **
** ** SINE AND COSINE LOOKUP ** **
** **
```



```

D9 3100 I=1,5
ARG=A(I)*SFA(I)+91.0
IARG=ARG
SA(I)=TRIG(IARG)+(ARG-IARG)*(TRIG(IARG+1)-TRIG(IARG))
CA(I)=TRIG(IARG+90)+(ARG-IARG)*(TRIG(IARG+91)-TRIG(IARG+90))
3100 CONTINUE
PS=P*CA(1)+R*SA(1)*SF21
RS=-P*SA(1)/SF21+R*CA(1)
PSB=PS*B2/V
CSB=QS*CB2/V
RSB=RS*B2/V
ADBTB(1)=-ADBTN(1)*CB2/V
*****
*
*
*
*****
C9EFFICIENT LOOKUP
*****
ALPHA=A(1)*SF8/5.0+6.0
IALPHA=ALPHA
BETA=A(2)*SF9/10.0+5.0
IBETA=BETA
IF(IALPHA.GT.14) IALPHA=14
IF(IALPHA.LT.1) IALPHA=1
IF(IBETA.GT.8) IBETA=8
IF(IBETA.LT.1) IBETA=1
D9 3200 I=1,4
C(I)=C9EFAB(I,IALPHA,IBETA)+(ALPHA-IALPHA)*(C9EFAB(I,IALPHA+1,IBET
XA)-C9EFAB(I,IALPHA,IBETA))+(BETA-IBETA)*(C9EFAB(I,IALPHA,IBETA+1)-
XC9EFAB(I,IALPHA,IBETA))
3200 CONTINUE
D9 3300 I=5,24
C(I)=C9EFA(I,IALPHA)+(ALPHA-IALPHA)*(C9EFA(I,IALPHA+1)-C9EFA(I,IAL
XPHA))
3300 CONTINUE
*****

```



```
* * *
**      RESOLUTION OF AERODYNAMIC FORCES AND MOMENTS
***
*****
***** FXAM=QUE*C(5)
***** FYAM=QUE*(C(4)+RSB*C(18)+PSB*C(15)+DR*C(9)+DA*C(12))
***** FZAM=QUE*(C(6)+QSB*C(21)+ADPTB(1)*C(23)+DIT*C(7))
***** FXSM=(TM-GEE*SA(4))*CA(1)+GEE*CA(4)*CA(5)*SA(1)+FXAM
***** FYSM=GEE*CA(4)*SA(5)+FYAM
***** FZWM=-(TM-GEE*SA(4))*SA(1)+GEE*CA(4)*CA(5)*CA(1)+FZAM
***** VDGT=FXSM*CA(2)+FYSM*SA(2)
***** FYVM=-FXSM*SA(2)+FYSM*CA(2)
***** ADGTN(1)=-FZWM*Sf31/(V*CA(2))+PS*SA(2)*Sf25/CA(2)-QS
***** ADGTN(2)=-FYVM*Sf32/V+RS
***** ADGTN(3)=-(R*CA(5)+Q*SA(5)*Sf26)/CA(4)
***** ADGTN(4)=-Q*CA(5)+R*SA(5)/Sf26
***** ADGTN(5)=-P+ADGTN(3)*SA(4)*Sf21
***** ALSI=(C(1)+PSB*C(16)+RSB*C(19)+DA*C(13)+DR*C(10))*QUE
***** AMI=(C(2)+QSB*C(22)+ADPTR(1)*C(24)+DIT*C(8))*QUE
***** ANSI=(C(3)+PSB*C(17)+RSB*C(20)+DA*C(14)+DR*C(11))*QUE
***** ALI=ALSI*CA(1)-ANSI*SA(1)*Sf21
***** ANI=ALSI*SA(1)/Sf21+ANSI*CA(1)
***** SDGT(1)=V*CA(4)*CA(3)
***** SDGT(2)=V*CA(4)*SA(3)*Sf33
***** SDGT(3)=V*(-SA(4)+SA(1)*CA(4)*CA(5))*Sf34
***** SX=-SXN*Sf13
***** SY=SYN*Sf14
***** SZ=-SZN*Sf15
***** AGA=A(1)*Sf8
*****
***** INITIALIZE AND CHOP RUNWAY IF AFT SF VIEWING CONE
*****
***** PP11=PP21=PP61=0.0
*****
* * *
```



```

ASZ=ABS(SZ)
YMID=(-A(4)*SF11-90.0+CEN1*ATAN(SQRT(ASZ)*CEN3/ASZ))/(DEGMX*CCA5)
D=2.5*SSA5
XSTART(8)=2.5*CCA5
YSTART(8)=YMID+D
XEND(8)=-XSTART(8)
YEND(8)=YMID-D
*****
*
*
*
*
SOFTWARE WINDOW
*****
DO 500 I=1,8
  IX1=XSTART(I)
  IX2=XEND(I)
  IY1=YSTART(I)
  IY2=YEND(I)
  IF(IX1.GE.1.AND.IX2.GE.1) GO TO 261
  IF(IX1.LE.-1.AND.IX2.LE.-1) GO TO 261
  IF(IY1.GE.1.AND.IY2.GE.1) GO TO 261
  IF(IY1.LE.-1.AND.IY2.LE.-1) GO TO 261
  IAGN=1
  X=XSTART(I)
  Y=YSTART(I)
  IX=IX1
  IY=IY1
  SLOPE=(YSTART(I)-YEND(I))/(XSTART(I)-XEND(I))
201 IF(IX)211,212,213
211 VINSCT=Y+SLOPE*(-1.-X)
221 IF(ABS(VINSCT).LE.1.) GO TO 226
223 IF(IY)224,261,225
226 XTEMP=-1.
    GO TO 247
224 HINSCT=X+(-1.-Y)/SLOPE
    YTEMP=-1.
*****

```



```

222 IF(ABS(HIN SCT).GT.1.) GO TO 261
   XTEMP=HIN SCT
   GO TO 250
225 HIN SCT=X+(1.-Y)/SLOPE
   YTEMP=1.
   GO TO 222
212 IF(IY)224,232,225
232 XTEMP=X
   YTEMP=Y
   GO TO 250
213 VIN SCT=Y+SLOPE*(1.-X)
   IF(ABS(VIN SCT).LE.1.) GO TO 246
   GO TO 223
246 XTEMP=1.
247 YTEMP=VIN SCT
250 GO TO (251,260),IAGN
251 X=XEND(I)
   Y=YEND(I)
   IX=IX2
   IY=IY2
   IAGN=2
   XSTART(I)=XTEMP
   YSTART(I)=YTEMP
   GO TO 201
260 CONTINUE
   XEND(I)=XTEMP
   YEND(I)=YTEMP
   GO TO 500
261 XEND(I)=-1.
   XSTART(I)=-1.
   YEND(I)=-1.
   YSTART(I)=-1.
500 CONTINUE

```

```

*****
*

```



```

ENC0DE(20,902,ITEX92)
ENC0DE(16,903,ITEX33)
ENC9DE(28,904,ITEX94)
ENC0DE(20,905,ITEX95)
ENC0DE(24,908,ITEX98)
ENC9DE(8,970,ITEX70)
ENC9DE(16,972,ITEX72)
ENC9DE(24,973,ITEX73)
ENC0DE(8,974,ITEX74)
ENC9DE(8,975,ITEX75)
ENC9DE(12,976,ITEX76)
ENC9DE(12,977,ITEX77)
ENC9DE(12,978,ITEX78)
CALL TEXT0(IDEV,ITEX91,4,1,25,3,3,IER)
IF(SNKRT.GT.20.0) G0 T0 1200
IF(-SX.GT.PP41) G0 T0 1200
IF((-SX.GT.1.0).AND.(-SX.LE.PP41)).AND.(-SY.GT.PP62)) G0 T0 1200
IF((-SX.GT.1.0).AND.(-SX.LE.PP41)).AND.(-SY.LT.PP22)) G0 T0 1200
IF(-SX.LE.1.0) G0 T0 1201
IF((-SX.GE.W1).AND.(-SX.LE.PP41)) G0 T0 1206
IF((-SX.GE.W2).AND.(-SX.LT.W1)) G0 T0 1205
IF((-SX.GE.W3).AND.(-SY.LT.W2)) G0 T0 1204
IF((-SX.GE.W4).AND.(-SX.LT.W3)) G0 T0 1203
IF(-SX.LT.W4) G0 T0 1202
1200 CALL TEXT0(IDEV,ITEX92,5,5,22,3,3,IER)
LL=-1
G0 T0 1300
1201 CALL TEXT0(IDEV,ITEX94,7,5,10,3,3,IER)
LL=-1
G0 T0 1300
1202 CALL TEXT0(IDEV,ITEX93,4,5,25,3,3,IER)
LL=1
G0 T0 1300
1203 IWIRE=4
G0 T0 1220

```



```

1204 IWIRE=3
    GO TO 1220
1205 IWIRE=2
    GO TO 1220
1206 IWIRE=1
1220 CALL TEXT0(IDEV,ITEX95,5,5,24,3,3,IER)
    ENCODE(16,906,ITFX96)IWIRE
    CALL TEXT0(IDEV,ITEX96,4,8,28,3,3,IER)
    LL=1
1300 IF((SNKRT.GT.18.0).AND.(SNKRT.LE.20.0).AND.(LL.GT.0)) CALL TEXT8
    X(IDEV,ITEX98,6,13,18,3,3,IER)
    ENCODE(28,907,ITEX97)SNKRT
    CALL TEXT0(IDEV,ITEX97,7,18,9,3,3,IER)
    IF(LL.EQ.-1) GO TO 1399
    CALL TEXT0(IDEV,ITEX70,2,23,37,3,3,IER)
    IF(SY.GT.1.0) GO TO 1310
    IF(SY.LT.-1.0) GO TO 1320
    CALL TEXT0(IDEV,ITEX72,4,28,28,3,3,IER)
    GO TO 1399
1310 ENCODE(32,909,ITEX99)SY
    CALL TEXT0(IDEV,ITEX99,8,28,4,3,3,IER)
    GO TO 1399
1320 ENCODE(32,971,ITEX71)-SY
    CALL TEXT0(IDEV,ITFX71,8,28,3,3,3,IER)
1399 IF(LL.LT.0) GO TO 510
    CALL TEXT0(IDEV,ITEX73,6,33,16,3,3,IER)
    IF(ND.EQ.1) GO TO 1401
    IF(ND.EQ.2) GO TO 1402
    IF(ND.EQ.3) GO TO 1403
    IF(ND.EQ.4) GO TO 1404
    CALL TEXT0(IDEV,ITEX75,2,38,42,3,3,IER)
    GO TO 510
1401 CALL TEXT0(IDEV,ITEX78,3,38,31,3,3,IER)
    GO TO 510
1402 CALL TEXT0(IDEV,ITEX74,2,38,42,3,3,IER)

```



```

1403  G0 T0 510
      CALL TEXT0(IDEV,ITEX77,3,38,31,3,3,IER)
      G0 T0 510
1404  CALL TEXT0(IDEV,ITEX76,3,38,36,3,3,IER)
*****
*
*
*
*****
      PROGRAM OPTIONS
*****
510  I=1000000
      CALL DELAY
      CALL DTINIT(IDEV,ITDIR,20,IER)
      CALL DGINIT(IDEV,IDIR,3,IER)
      ENCODE(32,143,ITEX43)
      ENCODE(24,145,ITEX45)
      ENCODE(28,146,ITEX46)
      ENCODE(24,147,ITEX47)
      ENCODE(16,148,ITFX48)
      CALL TEXT0(IDEV,ITEX43,8,7,4,3,3,IER)
      CALL TEXT0(IDEV,ITEX45,6,10,16,3,3,IER)
      CALL TEXT0(IDEV,ITEX46,7,17,9,3,3,IER)
      CALL TEXT0(IDEV,ITEX47,6,20,14,3,3,IER)
      CALL TEXT0(IDEV,ITEX48,4,23,24,3,3,IER)
509  IF (TEST(2)*LT.0) G0 T0 509
      CALL SETLINES(5,-1.0,6,-1.0)
2    IF (TEST(3)*LT.0) G0 T0 1001
      IF (TEST(2)*GT.0) G0 T0 2
      CALL SETLINES(5,+1.0,6,+1.0)
512  CALL DGINIT(IDEV,IDIR,3,IER)
      CALL DTINIT(IDEV,ITDIR,20,IER)
      ENCODE(32,130,ITFX30)
      ENCODE(28,131,ITFX31)
      ENCODE(44,132,ITEX32)
      ENCODE(28,133,ITEX33)
      ENCODE(48,134,ITEX34)
*****

```



```

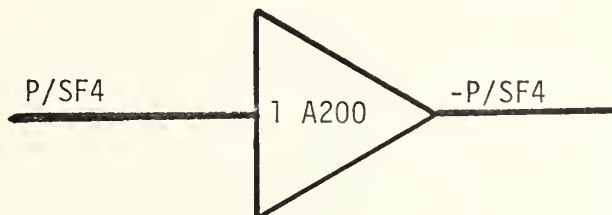
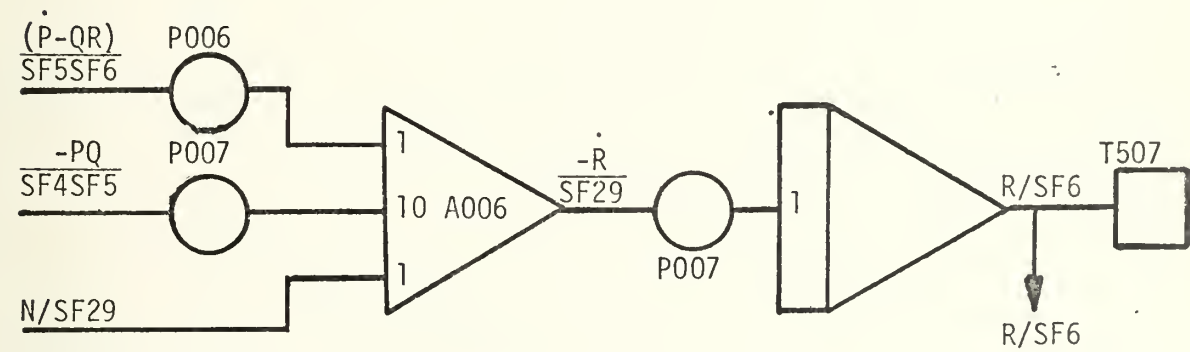
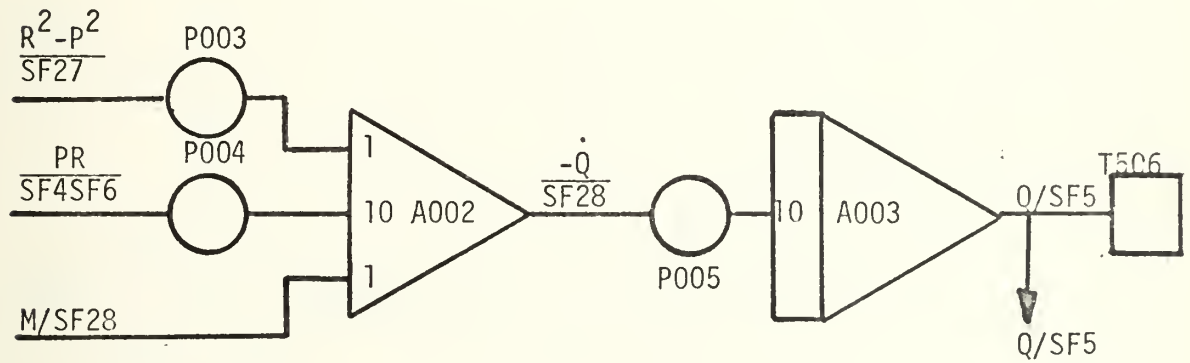
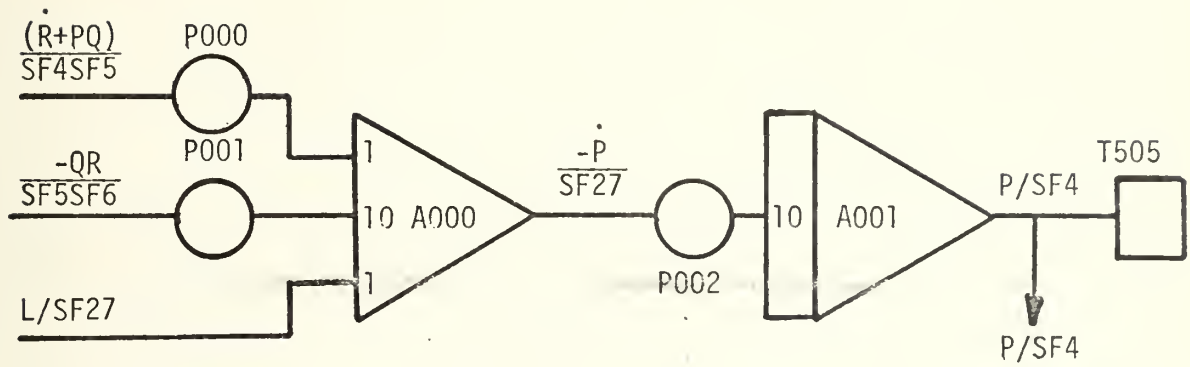
ENC0DE(4,135,ITEX35)
ENC0DE(12,136,ITEX36)
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ENC0DE(4,139,ITEX39)
ENC0DE(8,140,ITEX40)
ENC0DE(28,141,ITFX41)
ENC0DE(20,142,ITEX42)
CALL TEXT0(IDEV,ITEX30,8,1,8,2,3,IER)
CALL TEXT0(IDEV,ITEX31,7,3,8,2,3,IER)
CALL TEXT0(IDEV,ITEX32,11,7,1,2,3,IER)
CALL TEXT0(IDEV,ITEX33,7,9,4,2,3,IER)
CALL TEXT0(IDEV,ITEX34,12,13,1,2,3,IER)
CALL TEXT0(IDEV,ITFX35,11,15,4,2,3,IER)
CALL TEXT0(IDEV,ITEX36,3,17,4,2,3,IER)
CALL TEXT0(IDEV,ITEX37,12,21,1,2,3,IER)
CALL TEXT0(IDEV,ITFX38,11,23,4,2,3,IER)
CALL TEXT0(IDEV,ITEX39,11,25,4,2,3,IER)
CALL TEXT0(IDEV,ITEX40,2,27,4,2,3,IER)
CALL TEXT0(IDEV,ITEX41,7,31,1,2,3,IER)
CALL TEXT0(IDEV,ITEX42,5,33,1,2,3,IER)
NULL(1)=NULL(2)=77777777R
CALL TEXT0(IDEV,NULL,2,32,60,3,3,IER)
511 IF(M9D(ITDIR(14),8).EQ.C) 30 T0 511
CALL TEXT1(IDEV,CH0YC,2,0,14,IER)
631 FORMAT(F8.7)
DEC0DE(8,631,CH0YC)CH0YC
ICH0YC=CH0YC
IF(ICH0YC.LT.1) ICH0YC=4
60 T0 (8004,1001,8003,513),ICH0YC
513 CALL DGINIT(IDEV,IDIR,3,IER)
CALL DTINIT(IDEV,ITDIR,20,IER)
ENC0DE(24,144,ITEX44)
CALL TEXT0(IDEV,ITEX44,6,20,16,3,3,IER)
I=300000

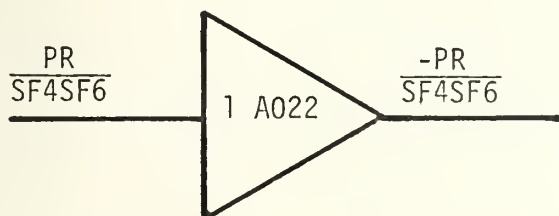
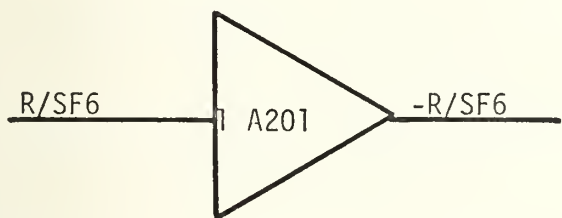
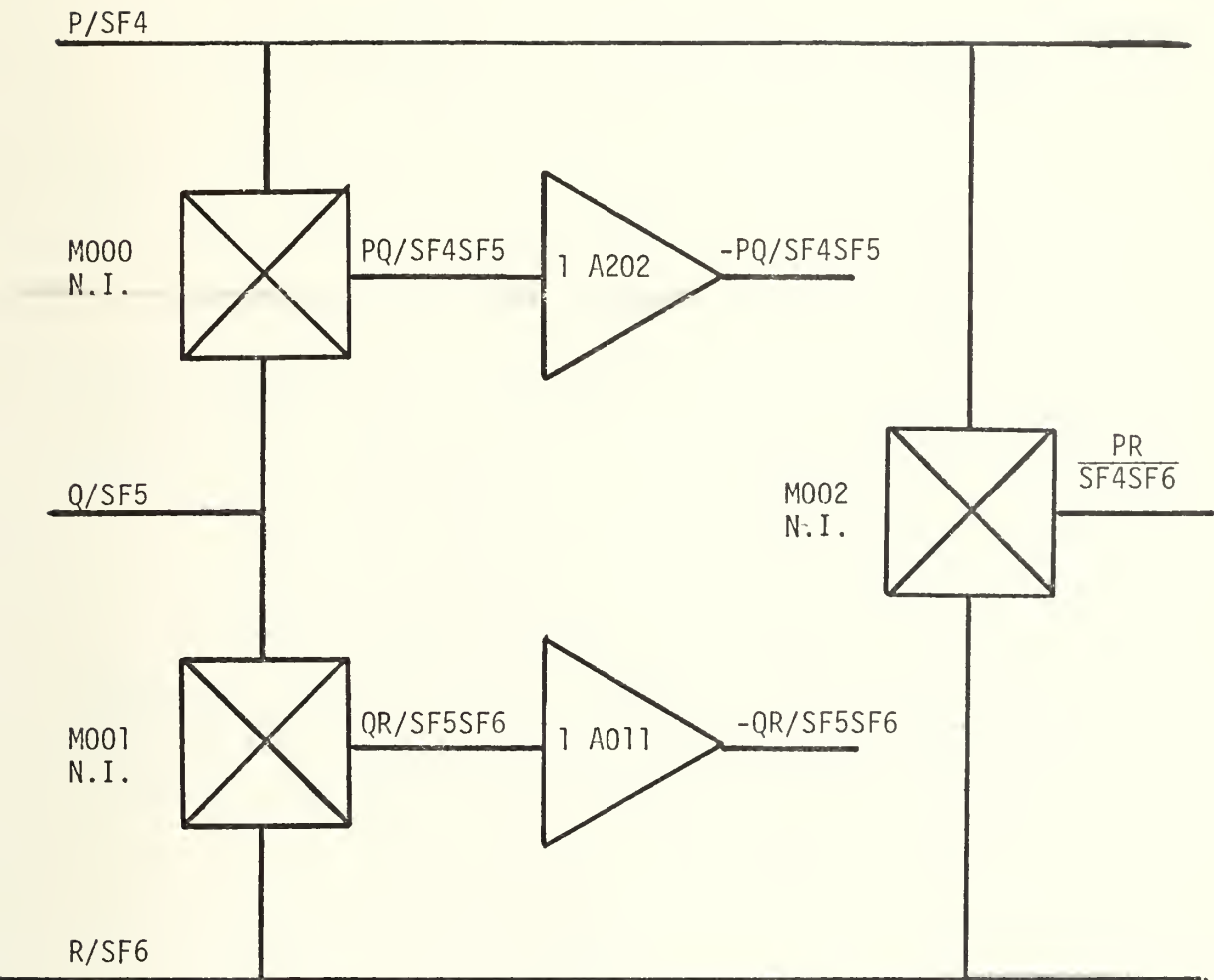
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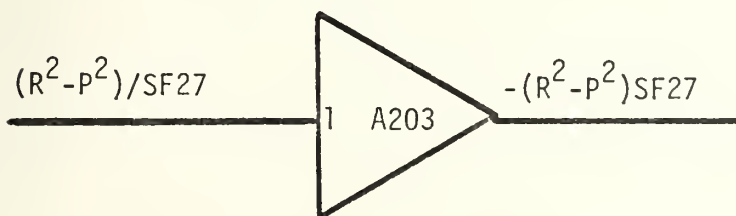
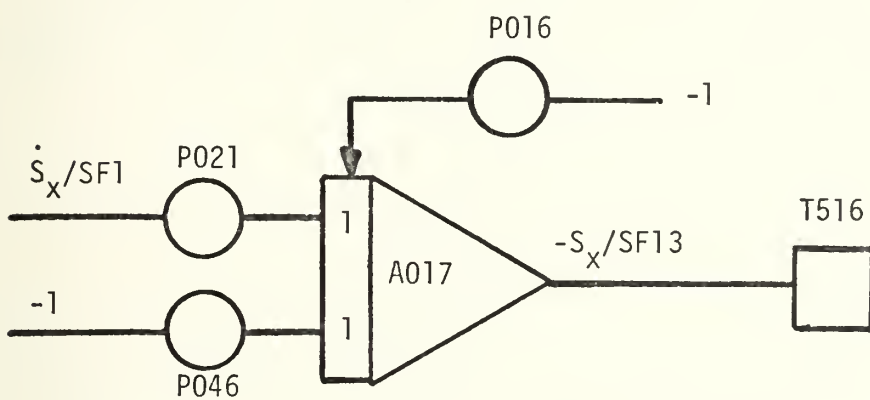
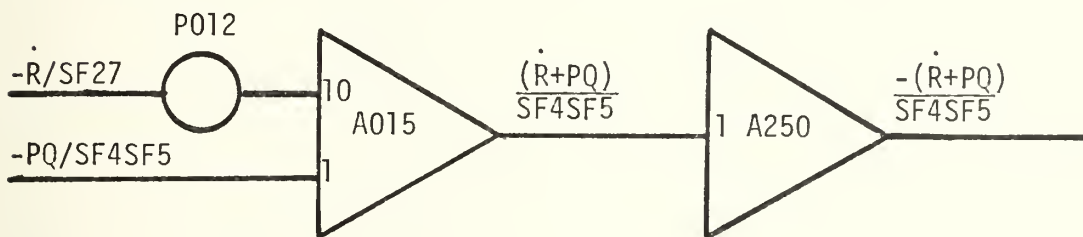
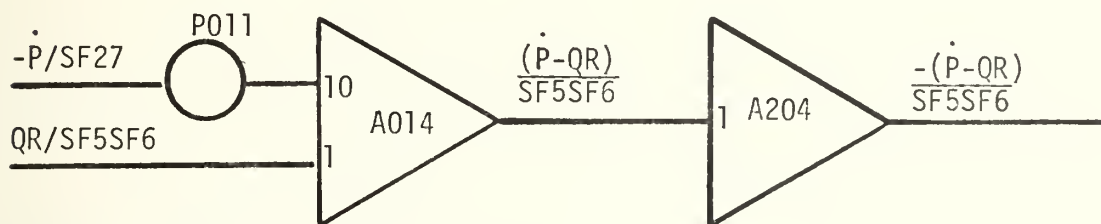
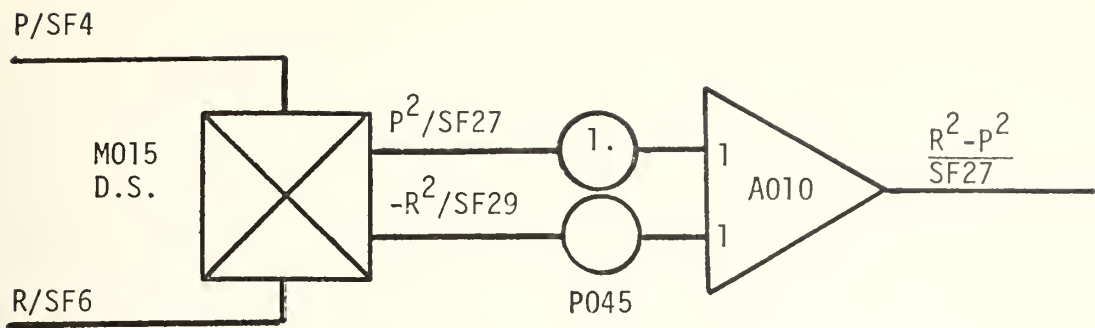

CALL DELAY
G0 T0 512
8004 CALL P0TSET
CALL DTINIT(IDEV,ITDIR,20,IER)
CALL DGINIT(IDEV,IDIR,3,IER)
STOP
END

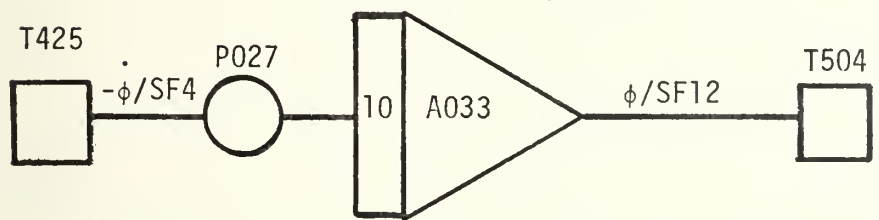
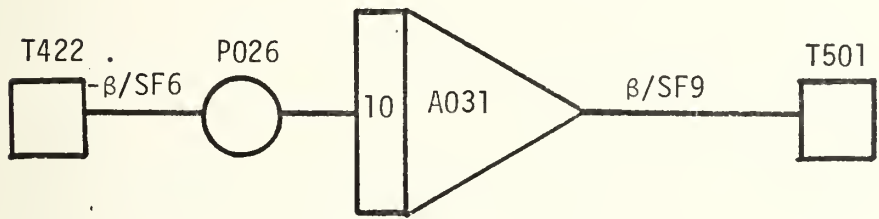
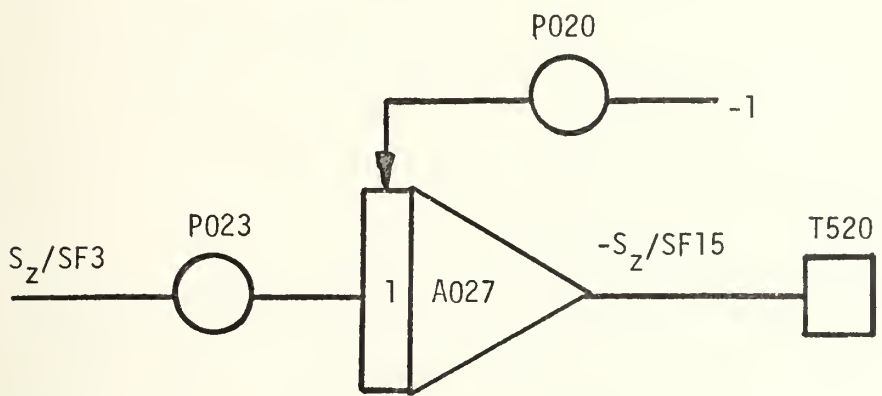
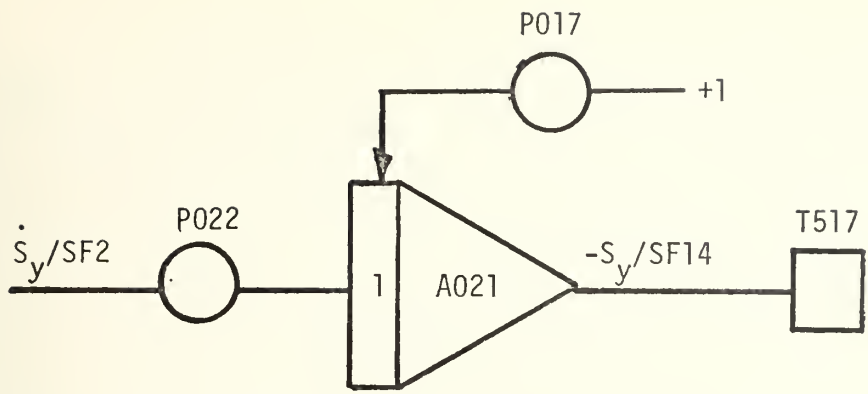
| | | |
|------|------|------------|
| IT0R | SKN | FINFLG |
| | BRU | \$-1 |
| | LDA | ADBUF,1 |
| | COPY | (0,B) |
| | FLA | 0,0 |
| | STD | *AD |
| | MPT | AD |
| | SKR | COUNT |
| | BRX | IT0R,1 |
| DTEA | LDA | *NDA |
| | MRG | =077700000 |
| | COPY | (A,X1) |
| | COPY | (0,A) |
| | STA | DACBM,1 |
| | BRX | \$+2,1 |
| | BRR | ADDA |
| | STZ | DCH |
| | BRU | \$+2 |
| RT0I | MPT | DA |
| | MP0 | DCH |
| | LDP | *DA |
| | CRSD | 9 |
| | ARSD | 15 |
| | COPY | (-A,A) |
| | COPY | (A,X2) |
| | COPY | (B,A) |
| | ARSA | 0,2 |
| | ETR | =077777000 |
| | ADD | DCH |
| | STA | DACBM,1 |
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| | LDA | *NDA |
| | LLSA | 15 |
| | ADD | =DACBM |

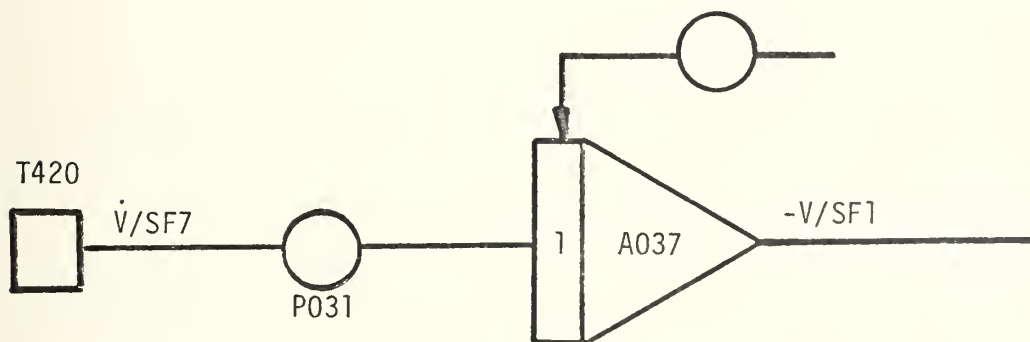
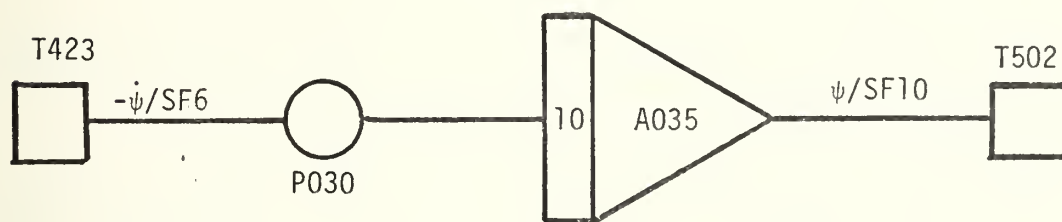
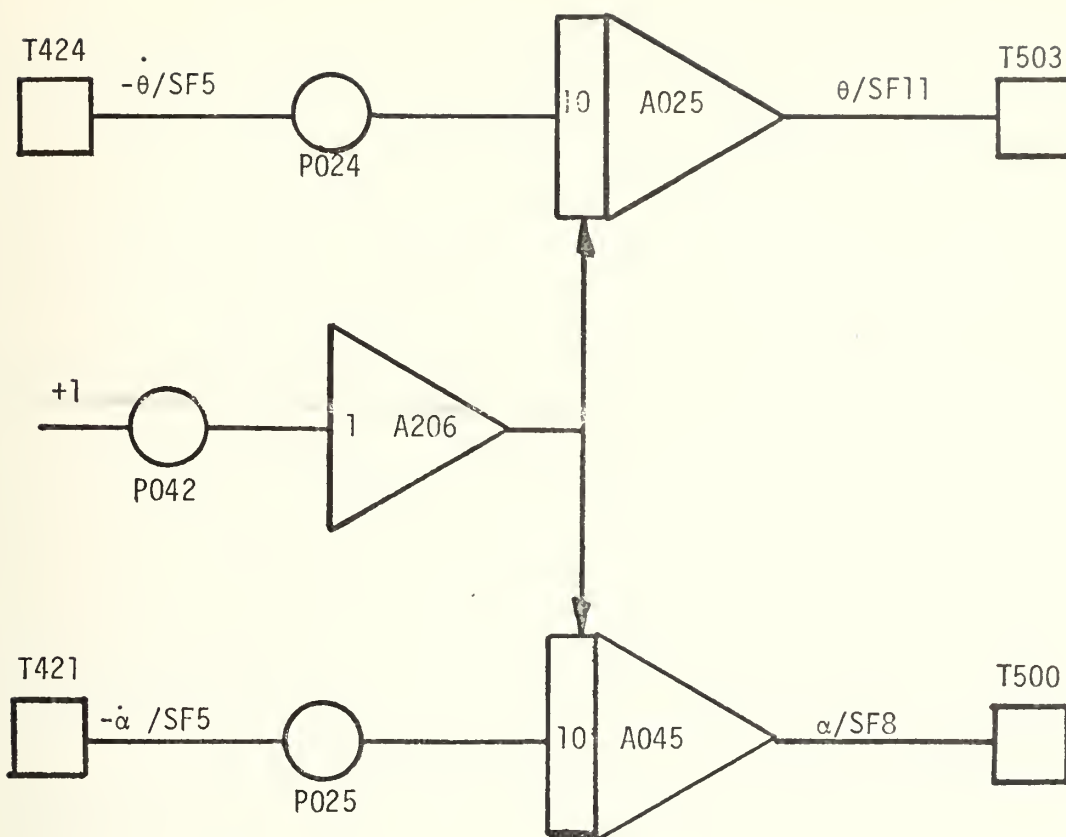
APPENDIX B - THE ANALOG PROGRAM

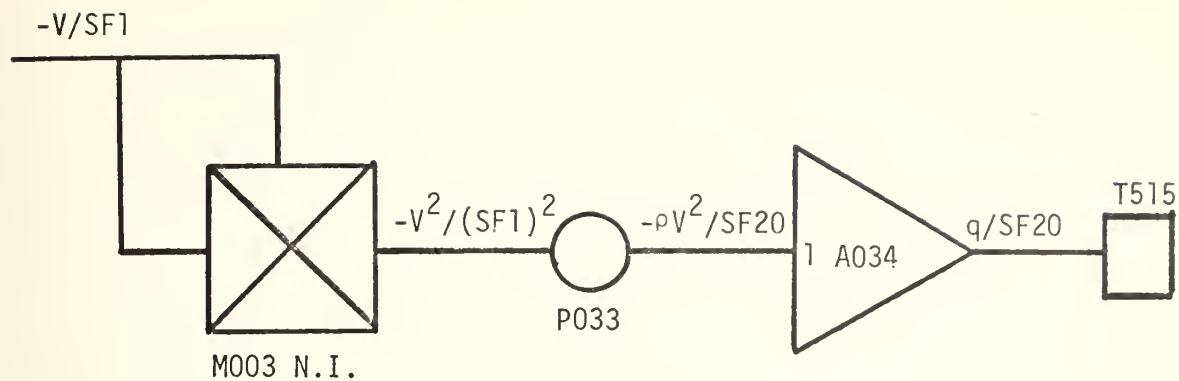




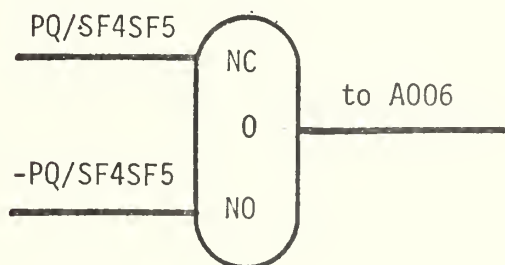
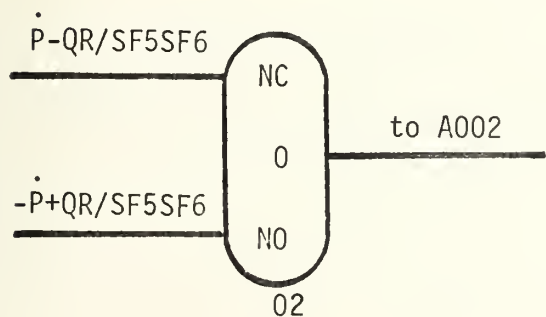
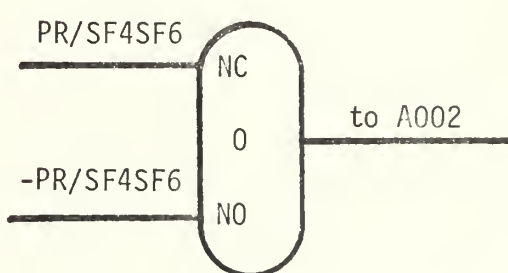
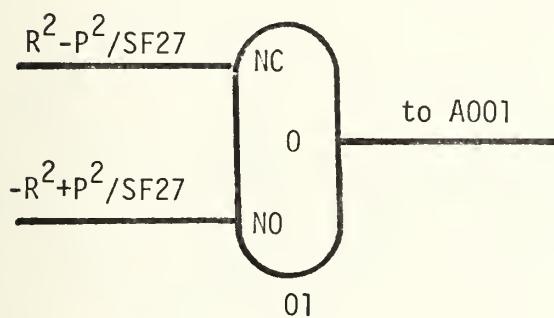
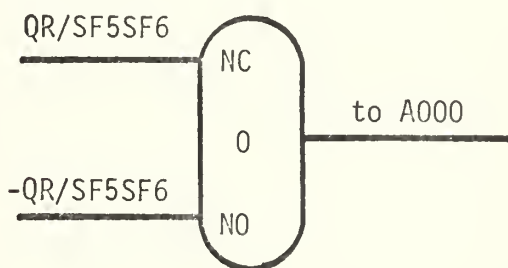
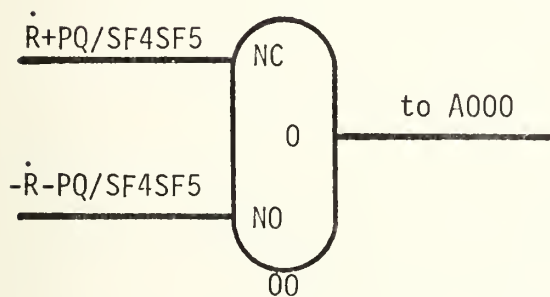


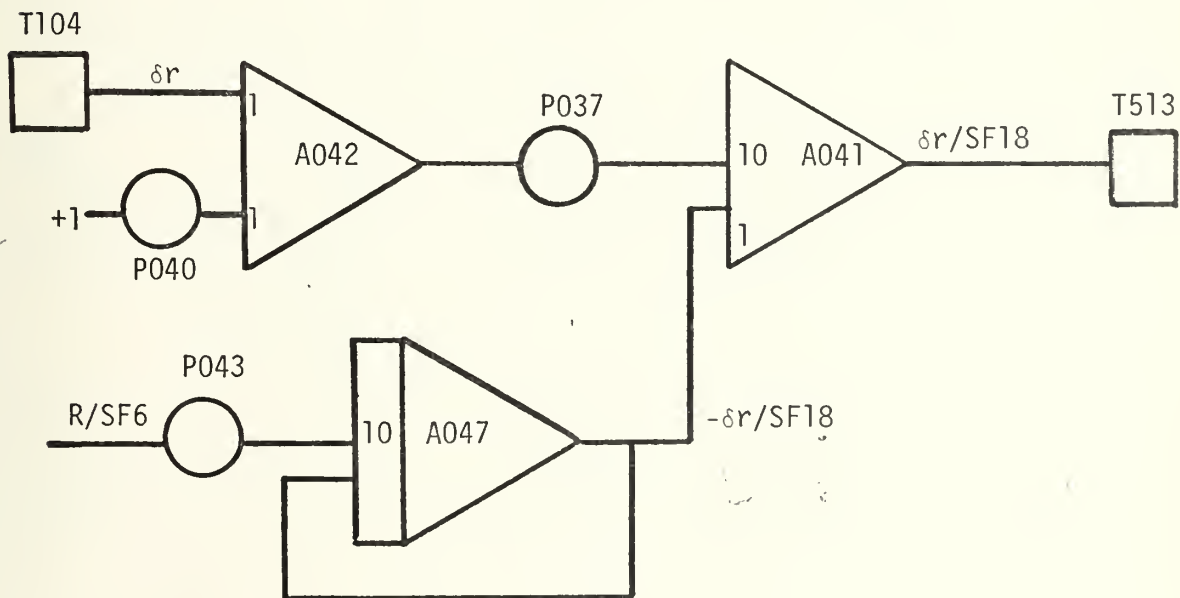
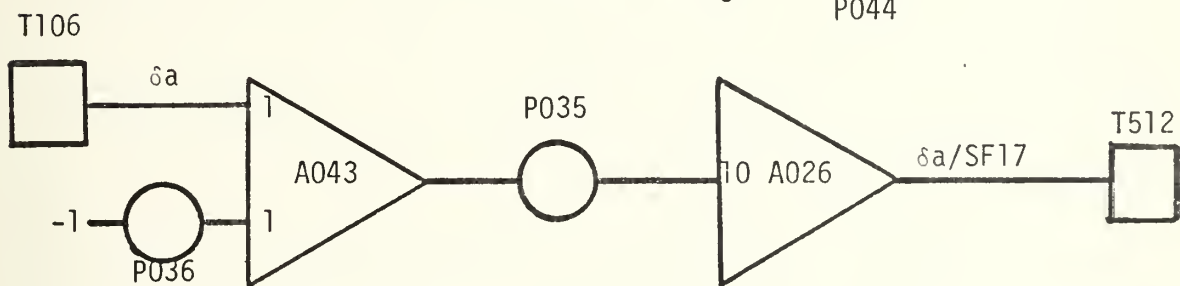
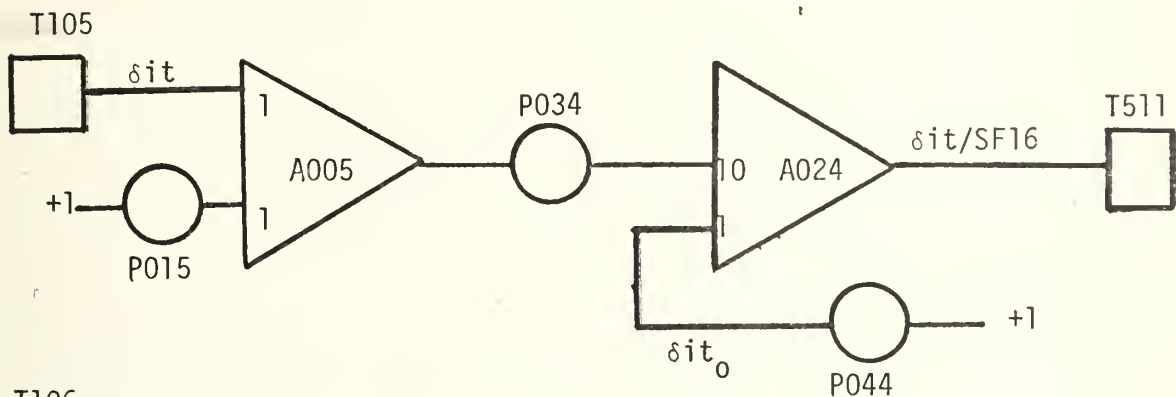
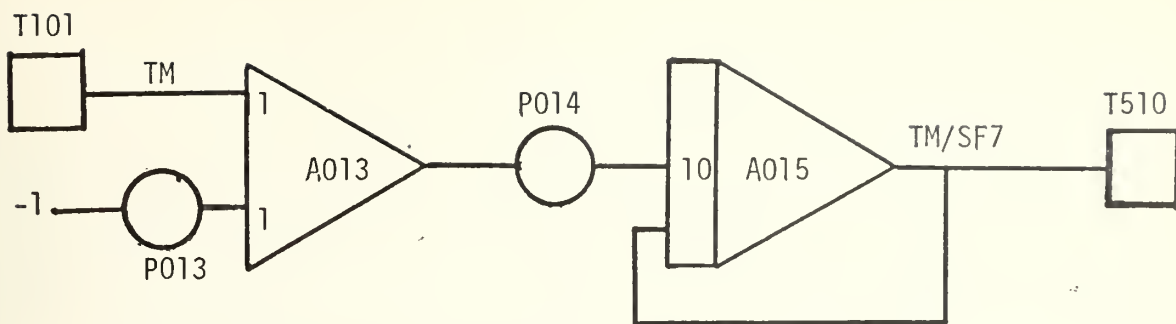




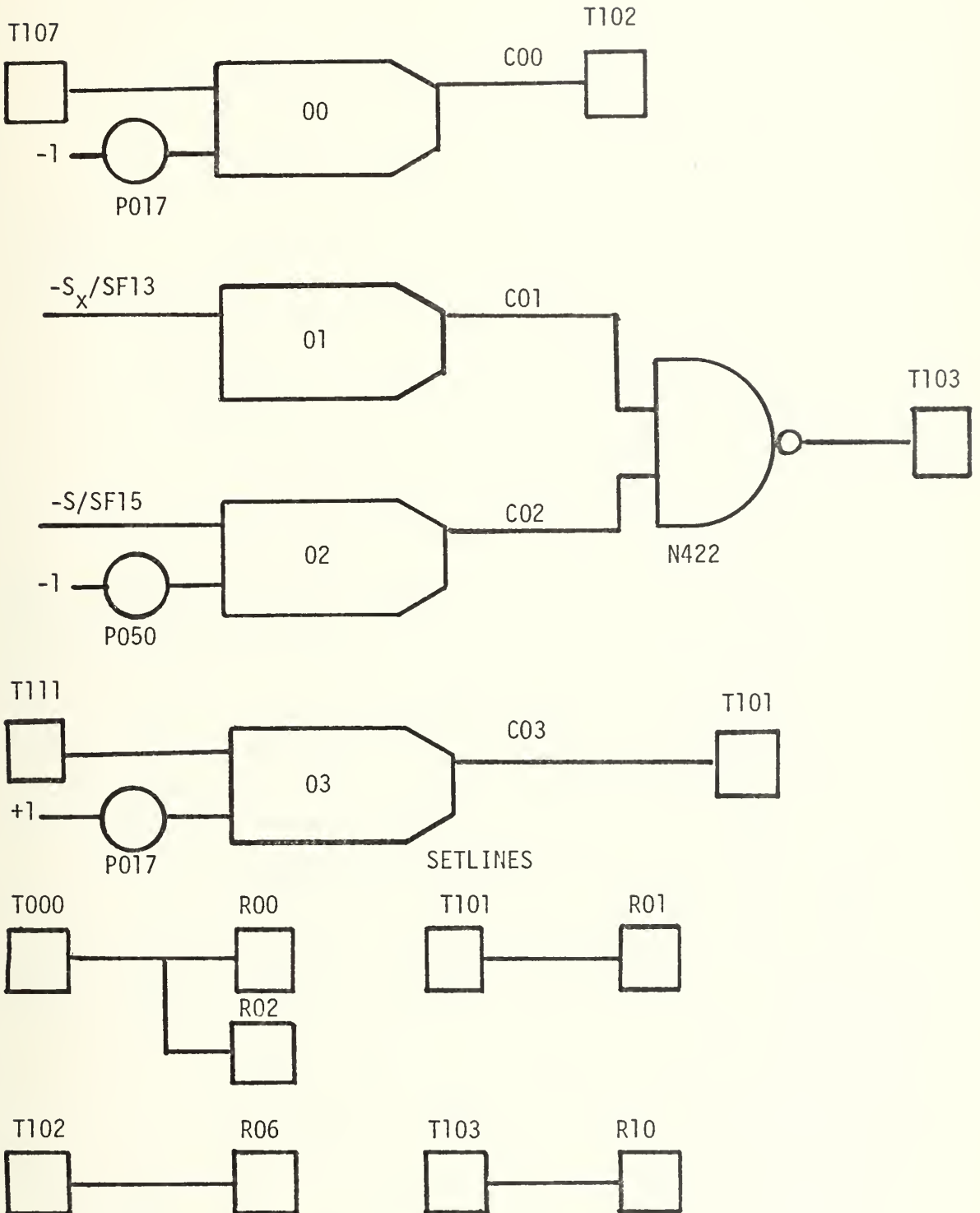


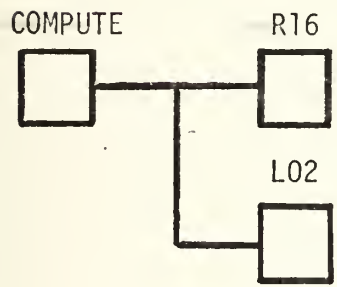
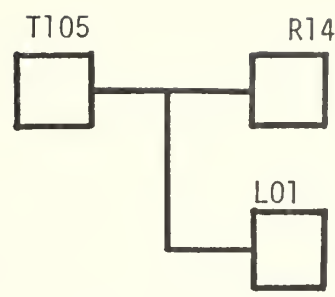
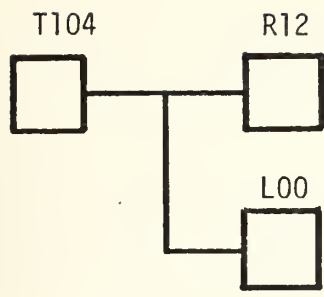
DPDT SWITCHES



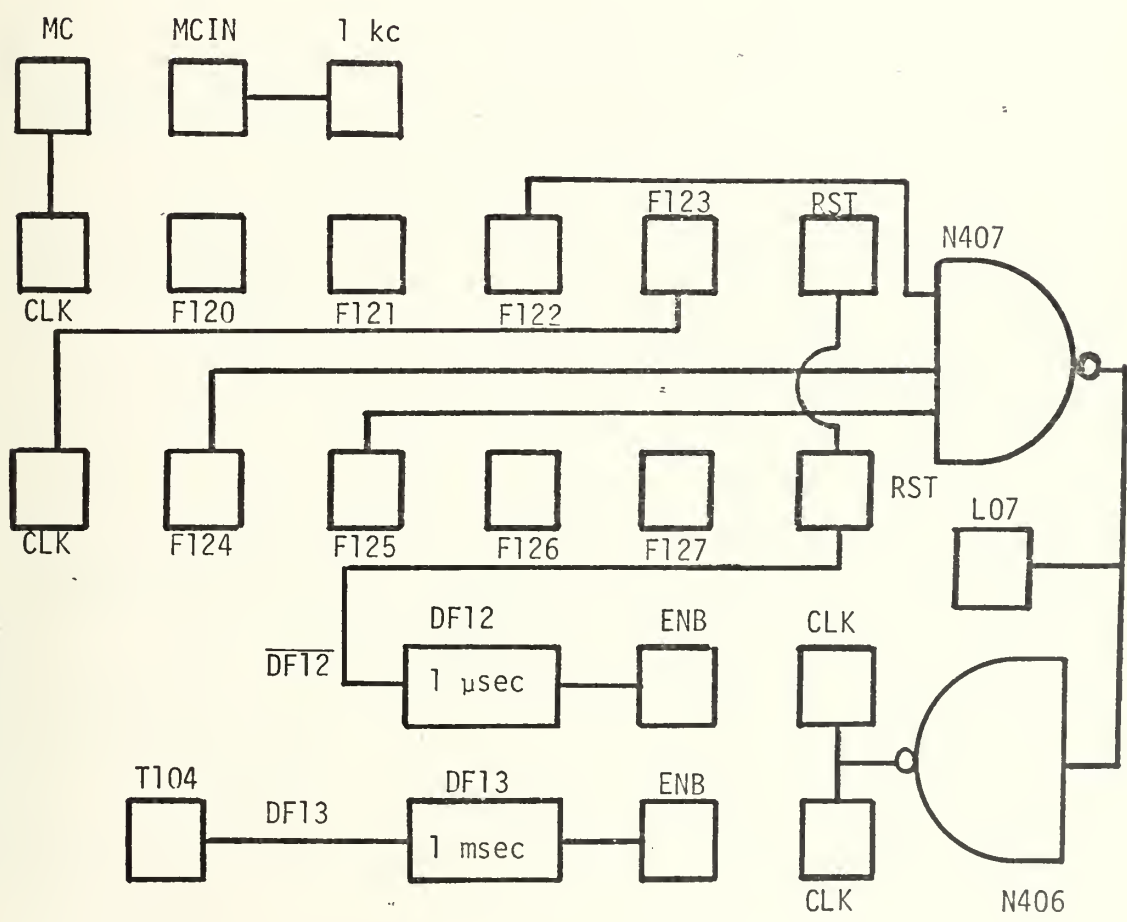


COMPARATORS

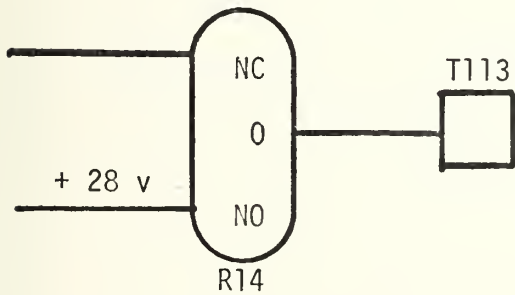
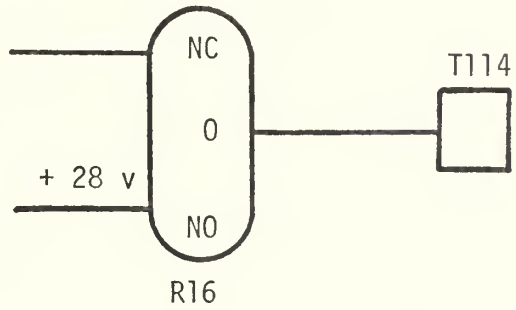
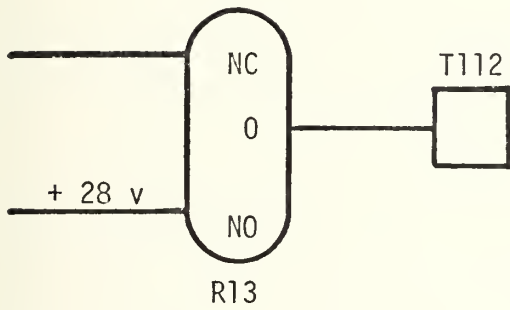
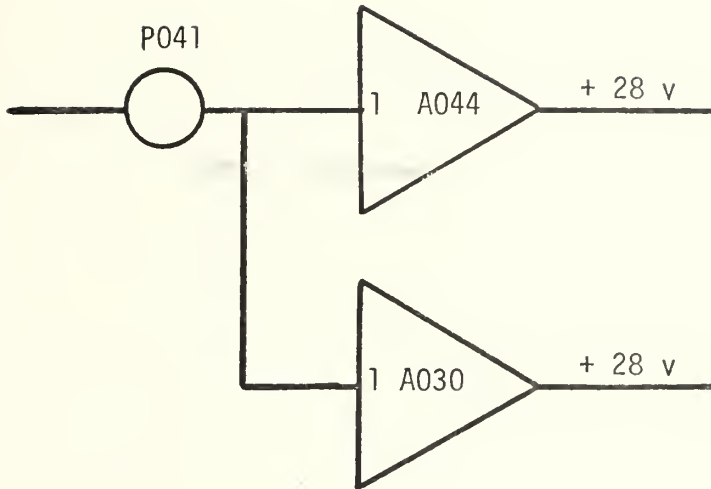




BINARY COUNTER



POWER FOR LIGHTS



APPENDIX C - PROGRAM VARIABLES

The following is an alphabetic listing of the program variables used in the simulator program.

A - Array of angles, in order, alpha, beta, psi, theta, and phi

A10 - Initial conditions on A(1), the angle of attack

AA - Array of analog to digital variables

AD - Array of analog to digital variables

ADOTB - Normalized time derivative of the angle of attack

ADOTN - Array of the negatives of the time derivatives of the angles
in A

ADOTO - Temporary storage for ADOTN during the predict and update phase
of the program

ALI - Aerodynamic rolling moment about the body axis

ALPHA - Real argument based on angle of attack and used for coefficient
lookup

ALSI - Aerodynamic rolling moment about the stability axis

AMI - Aerodynamic pitching moment about the body axis

ANI - Aerodynamic yawing moment about the body axis

ANSI - Aerodynamic yawing moment about the stability axis

AOA - Actual angle of attack in degrees

AOAF - Angle of attack break point for fast chevron

AOALDG - Optimum landing angle of attack

AOALF - Angle of attack break point for fast chevron and donut

AOALS - Angle of attack break point for slow chevron

ARG - Argument used during sine and cosine lookup (type real)

ASZ - Absolute value of SZ

B - Wing span

B2 - One half the wing span B

B3 - Scale factor divisor used to divide out the scale factor of the homogeneous transformation coordinates

BETA - Real argument based on side slip angle used in coefficient lookup

C - Array of aerodynamic coefficients for a given angle of attack and sideslip angle

CA - Array of cosines of the angle array A

CB - Mean aerodynamic chord

CB2 - One half the mean aerodynamic chord CB

CCA(n) - Scalar equivalents of the array CA

CHOYC - Choice of program options offered by main program

COEFA - Array of coefficients dependent on angle of attack only

COEFAB - Array of coefficients dependent on angle of attack and side slip angle

CON1 - Program constant equal to the number of degrees in a radian

CON2 - Program constant equal to .2 divided by .75

CON3 - Program constant used in computing the depression angle of the horizon

CON4 - Program constant equal to the sine of 30 degrees

CON5 - Program constant equal to the cosine of 30 degrees

CON6 - Program constant equal to the ratio of CON3 to CON5

D - Constant equal to 2.5 times the sine of the roll angle and used in calculating the horizon

DA - Aileron deflection

DEGA - Degrees of angle of attack for which COEFA and COEFAB are tabulated

DEGB - Degrees of side slip for which COEFAB are tabulated

DEGMAX - Max angle of the visibility cone formed by the square viewing window

DIT - Flying tail deflection

DITO - Initial flying tail deflection setting

DR - Rudder deflection

F - Focal length of viewing image

FXAM - Aerodynamic force in the X-direction divided by the mass of the aircraft

FXSM - Force in X-direction of the stability axis divided by the mass of the aircraft

FYAM - Aerodynamic force in the Y-direction divided by the mass of the aircraft

FYSM - Force in the Y-direction of the stability axis divided by the mass of the aircraft

FYWM - Force in the Y-direction of the wind axis divided by the mass of the aircraft

FZAM - Aerodynamic force in the Z-direction divided by the mass of the aircraft

FZWM - Force in the Z-direction of the wind axis divided by the mass of the aircraft

G - Acceleration due to gravity

GEE - Scaled acceleration due to gravity

GS - Glide slope in degrees

GS0 - Optimal glide slope

H - Graphic transformation matrix (H-Matrix) or array

H1 - First component array of the H-Matrix

H2 - Second component array of the H-Matrix

H3 - Third component array of the H-Matrix

HHnn - Scalar equivalent of the H-Matrix or array

HINSCT - Horizontal intersection of a line, used in the software window

HMIR - Height of Lens below the landing surface

I - Integer variable usually a counter

IA - Do-loop counter based on angle of attack

IAGN - A counter to check the number of times a point has gone through
the software window

IALPHA - Integer conversion of ALPHA

IARG - Integer conversion of ARG

IB - Do-loop counter based on the side slip angle

IBETA - Integer conversion of BETA

ICHOYC - Integer conversion of CHOYC

IDE - Graphic array containing the dynamic portion of the display

IDEV - Graphic device number (1 or 2)

IDIR - Graphic block directory for the graphics digital processor

IDON - Array of packed points for the donut portion of the indexer

IER - Error flag returned by graphic subroutines

IFAST - Packed graphic array of the fast chevron

IPLS - Integer counter equal to I plus one

ISF7 - Integer scale factor based on thrust divided by mass

ISLO - Packed graphic array of the slow chevron

ISQ - Array/graphics block of fixed data, basically the square or window

ITDIR - Text directory for the graphics digital processor

ITEXnn - Line of text that is sent from the digital computer to the
graphic digital processor

IWIRE - Wire caught on arrested landing
 IX - Operating values of start/end points (X-coordinate) used in software window
 IX1 - Equivalent of XSTART, used in software window
 IX2 - Equivalent of XEND, used in software window
 IY - Operating values of start/end points (Y-coordinate), used in software
 IY1 - Equivalent of YSTART, used in software window
 IY2 - Equivalent of YEND, used in software window
 J - Do-loop counter
 KK - Array of integers used in outputting coefficients
 KPOT - Array of integers used in outputting analog pot settings
 LL - Landing result flag
 NAD - Number of analog to digital conversion variables/trunk lines
 ND - Display flag based on present condition of the angle of attack indexer
 NDA - Number of digital to analog conversion variables/trunk lines
 NULL - Octal value used to null out a line of text
 P - Angular velocity of the aircraft about X-axis
 Pn - Array of runway points
 PDOTN - The negative of the time derivative of P
 POT - Array of pot settings for the analog
 PPnn - Scalar equivalents of Pn
 PS - P about the stability axis
 PSB - PS normalized
 Q - Angular velocity of the aircraft about the Y-axis
 QDOTN - The negative of the time derivative of Q

QS - Q about the stability axis

QSB - QS normalized

QUE - Dynamic pressure

R - Angular velocity about the Z-axis

RAMP - X-coordinate of the ramp of the runway

RDOTN - The negative of the time derivitative of R

RHO - Density of air

RIXX - Moment of inertia of the aircraft about the X-axis

RIXZ - Product of inertia about the X and Z-axis

RIYY - Moment of inertia of the aircraft about the Z-axis

RMASS - Mass of the aircraft

RS - R about the stability axis

RSB - RS normalized

S - Wing area of the aircraft

SA - Array of sines of the angle array A

SDOT - Array of time derivitives (velocities) of the distances in all
three inertial directions

SF1 - Scale factor based on maximum velocity in X-direction

SF2 - Scale factor based on maximum velocity in Y-direction

SF3 - Scale factor based on maximum velocity in Z-direction

SF4 - Scale factor based on maximum angular velocity in X-direction

SF5 - Scale factor based on maximum angular velocity in Y-direction

SF6 - Scale factor based on the maximum angular velocity in the Z-direction

SF7 - Scale factor based on thrust divided by mass of the aircraft

SF8 - Scale factor based on maximum angle of attack

SF9 - Scale factor based on the maximum side slip angle

SF10 - Scale factor based on the maximum yaw angle

SF11 - Scale factor based on the maximum pitch angle

SF12 - Scale factor based on the maximum roll angle

SF13 - Scale factor based on the maximum distance in the X-direction

SF14 - Scale factor based on the maximum distance in the Y-direction

SF15 - Scale factor based on the maximum distance in the Z-direction

SF16 - Scale factor based on the maximum flying tail deflection angle

SF17 - Scale factor based on the maximum aileron deflection angle

SF18 - Scale factor based on the maximum rudder deflection angle

SF19 - Scale factor based on the density of air

SF20 - Scale factor based on SF1 squared divided by SF19

SF21 - Ratio of SF6 to SF4

SF22 - Ratio of SF1 to SF4

SF23 - Ratio of SF1 to SF5

SF24 - Ratio of SF1 to SF6

SF25 - Ratio of SF4 to SF5

SF26 - Ratio of SF5 to SF6

SF27 - SF4 squared

SF28 - SF5 squared

SF29 - SF6 squared

SF30 - Feedback gain for yaw damper

SF31 - Scale factor based on SF7 divided by SF1 and SF5

SF32 - Scale factor based on SF7 divided by SF1 and SF6

SF33 - Ratio of SF1 to SF2

SF34 - Ratio of SF1 to SF3

SF35 - Scale factor based on ratio of SF5 to SF8

SF36 - Scale factor based on ratio of SF6 to SF9

SF37 - Scale factor based on ratio of SF6 to SF10

SF38 - Scale factor based on ratio of SF5 to SF11
SF39 - Scale factor based on ratio of SF4 to SF12
SF40 - Ratio of SF7 to SF1
SFA - Array of scale factors, made up to SF8 through SF12
SFACTR - Scale factor of the H-Matrix
SLOPE - Slope of a display line, used in software window
SNKRT - Sink rate of the aircraft in ft/sec at the conclusion of a run
SSAn - Scalar equivalents of SA
SX - Actual distance of aircraft in X-direction (inertial)
SX0 - Initial condition on SX
SXN - Normalized Distance of aircraft in X-direction (inertial)
SY - Actual distance of aircraft in Y-direction (inertial)
SYN - Normalized distance of aircraft in Y-direction (inertial)
SZ - Actual distance of aircraft in Z-direction (inertial)
SZ0 - Initial condition on SZ
SZN - Final cutoff value on SZ (height of eye)
T - Thrust of the aircraft
TALPHA - Tangent of the yaw angle
TAU - Time delay of the prediction and update
TM - Thrust divided by mass of aircraft
TPn - Temporary point number n
TRIG - Array of sines of various angles
TX - X-direction value used to chop the runway
V - Velocity
V0 - Initial condition on velocity V
VDOT - Time derivative of V
VDOTO - VDOT of the iteration before

VINSCT - Vertical intersection of a line, used in window

W - Weight of the aircraft

Wn - Wire position on runway

WIND - Velocity of the wind in knots

X - X value used in software window

XEND - Array of X-coordinate ending points of display lines

XMIR - X position of the lens

XSTART - Array of X-coordinate starting points of display lines

XTEMP - Temporary storage for X

Y - Y value used in software window

YEND - Array of Y-coordinate ending points of display lines

YMB - Y-coordinate of the "meatball"

YMID - Y intercept of the horizon

Y0 - H-Matrix offset in Y-direction

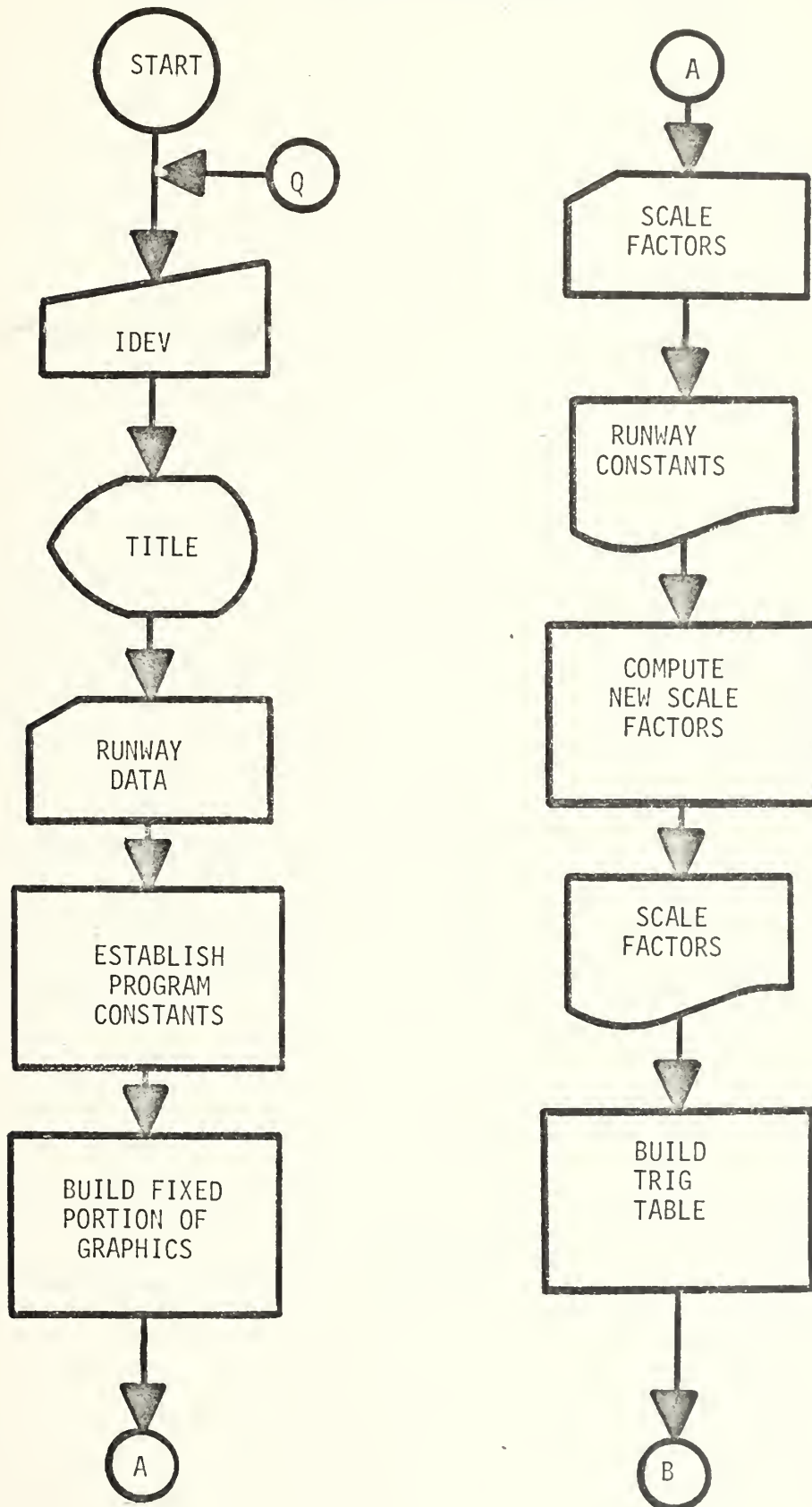
YSTART - Array of Y-coordinate starting points of display lines

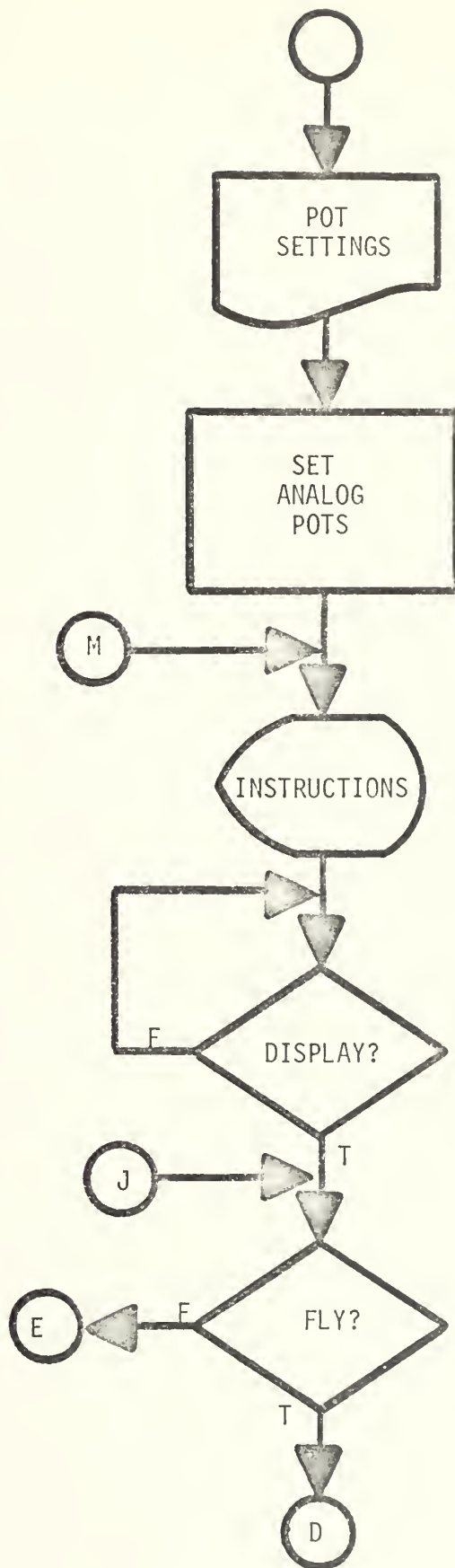
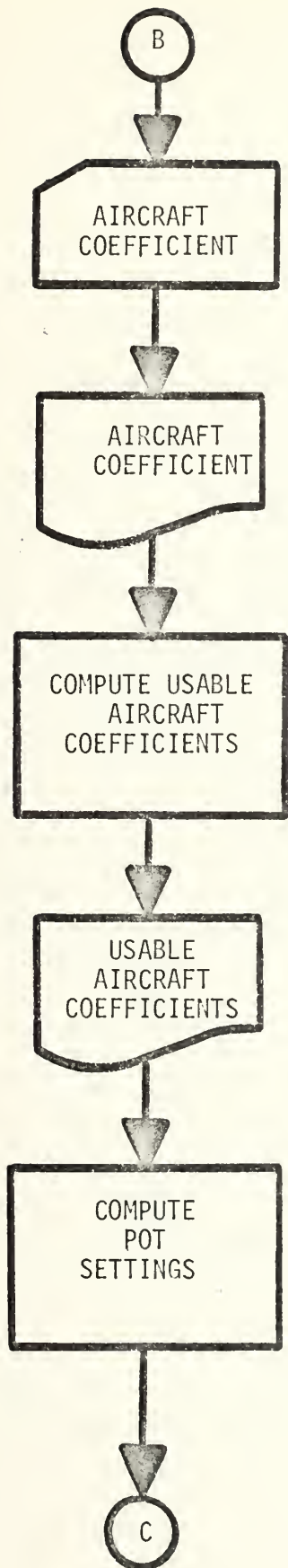
YTEMP - Temporary storage for Y-coordinate in software window

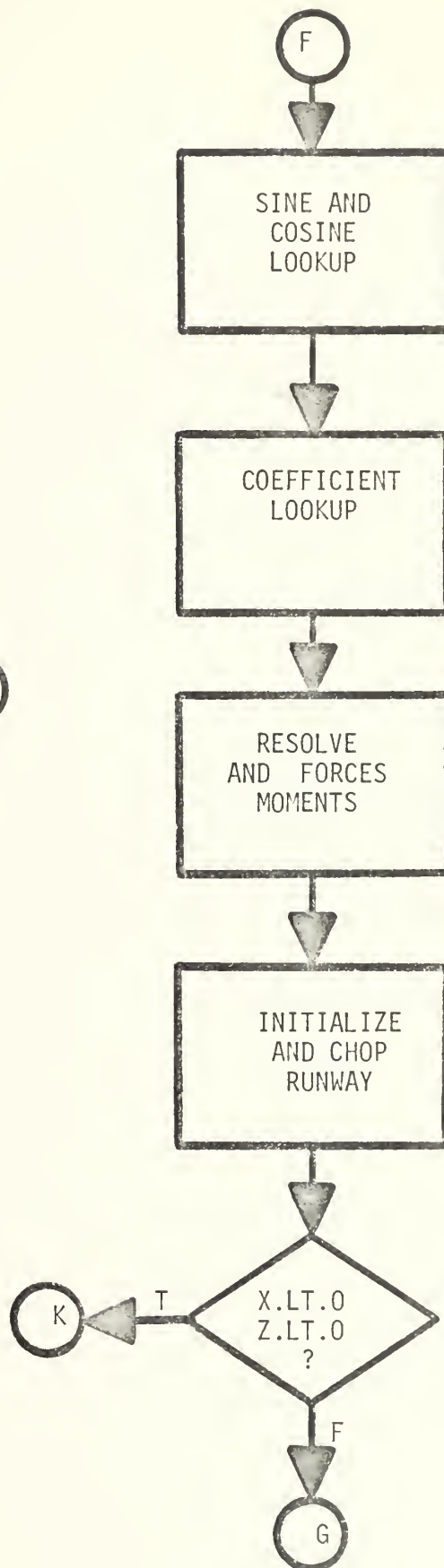
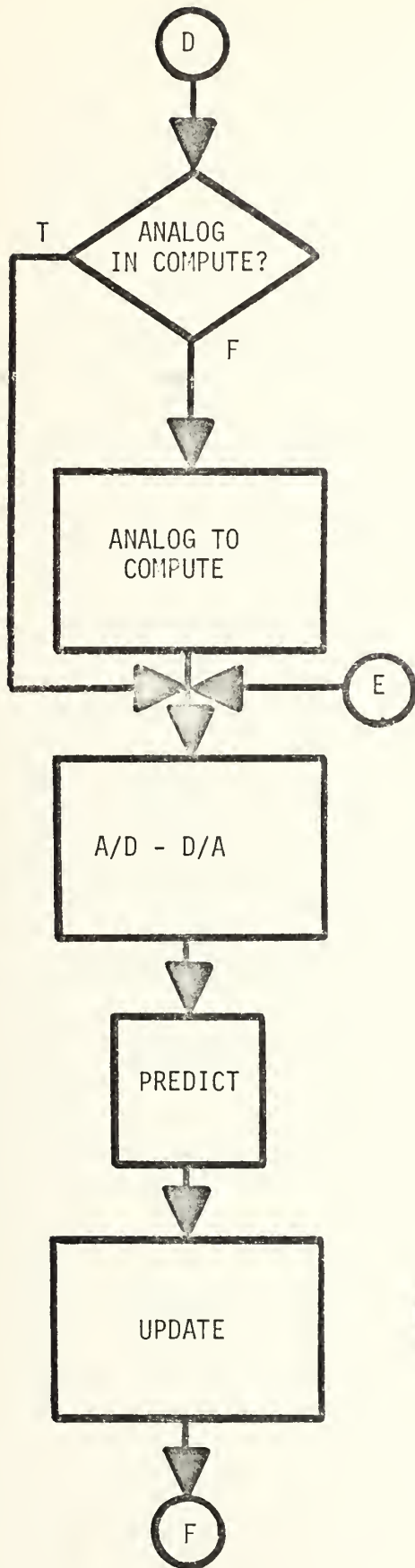
Z - Temporary storage array used in multiplying H1, H2, and H2 to yield
the H-Matrix

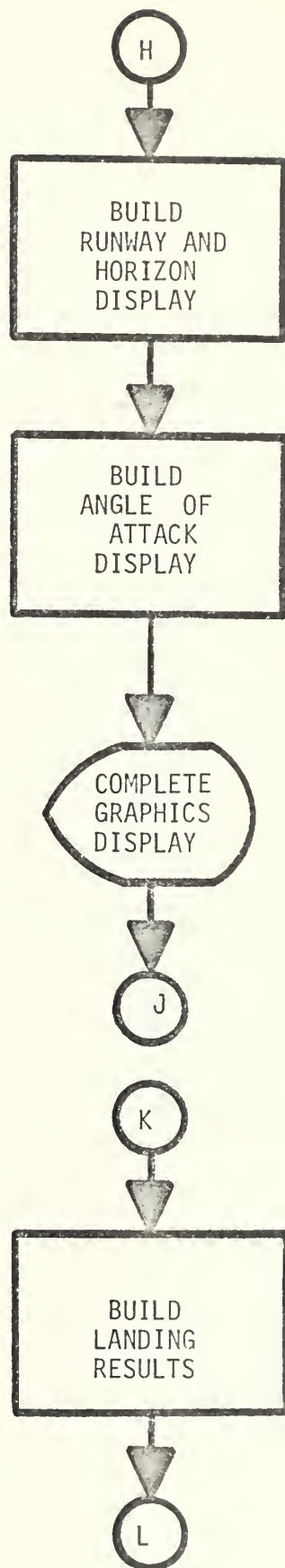
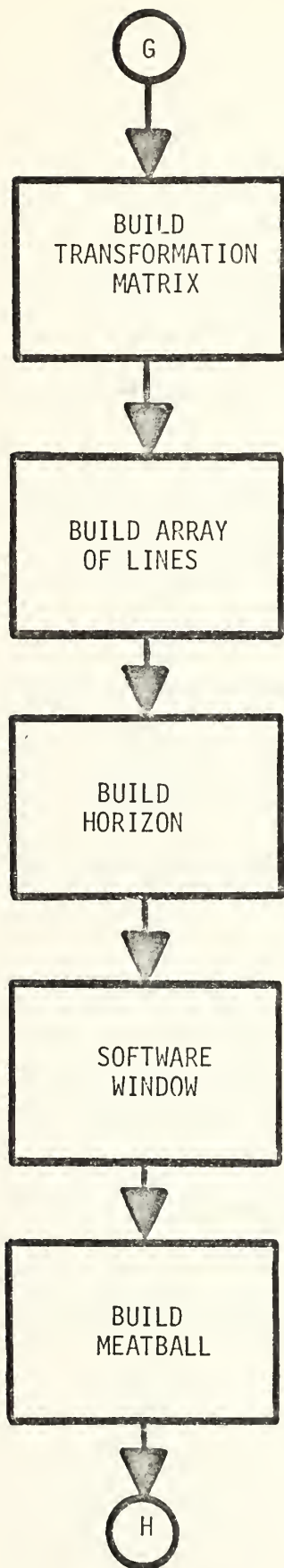
Z0 - H-Matrix offset in Z-direction

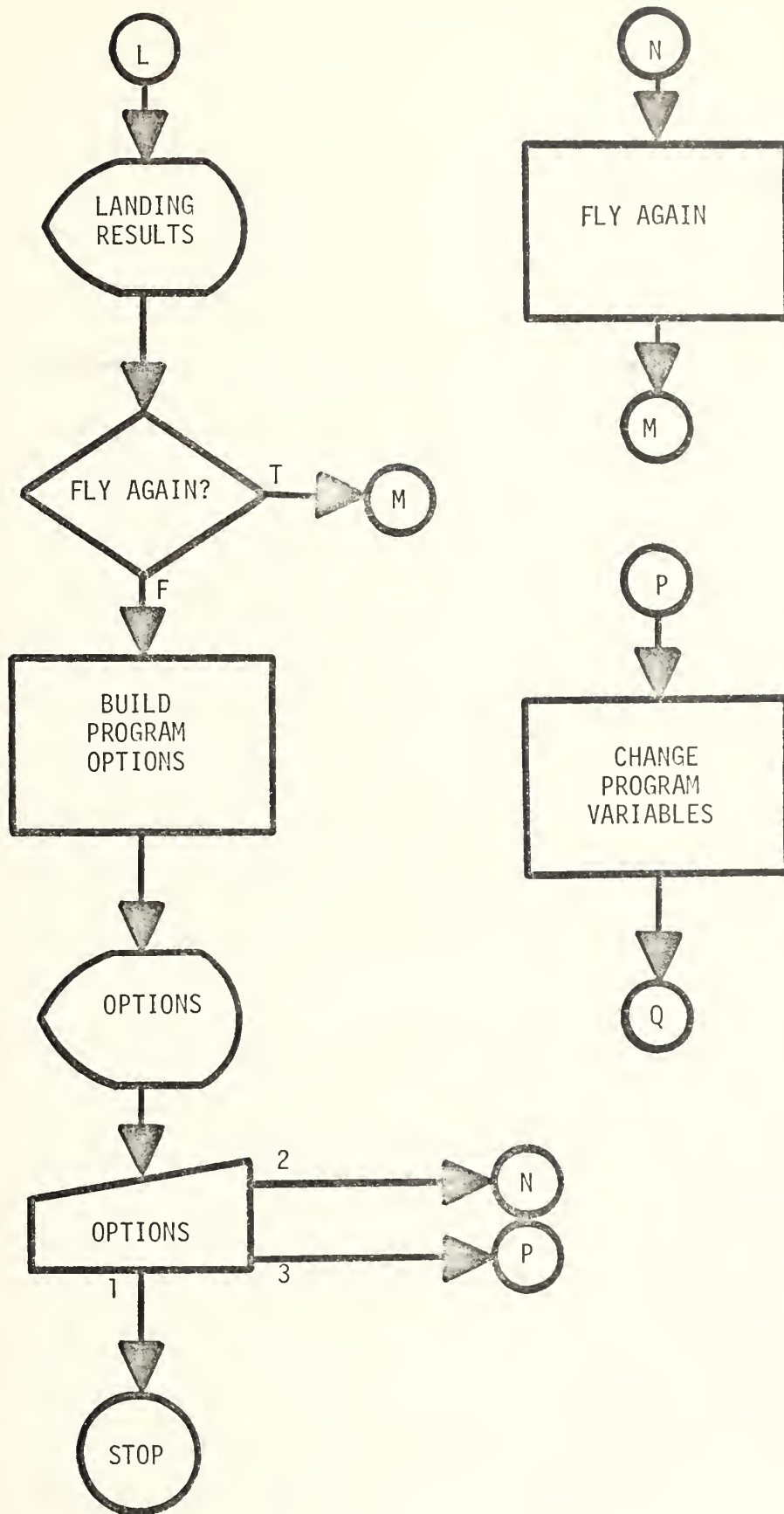
APPENDIX D - DIGITAL PROGRAM FLOW DIAGRAM











APPENDIX E - OPERATING MANUAL

The program exists on tape in two forms, one is in a Source deck format (SI) and must be compiled prior to execution. This takes approximately 15 minutes. This tape is stored in the tape locker and is titled CALS NEW VERSION. The other version is a core dump (SAVE) version. Just prior to the execution of the program, after the compilation and loading phases are complete, a copy of core is dumped on tape. Execution of this version (RERUN) is approximately 10 seconds. Again this is stored in the tape locker under the title of CALS CORE DUMP.

All the required cards for the program are filed in the file under CARRIER APPROACH LANDING SIMULATOR. The cards filed include the master version of the program, several data decks and the control cards for running any of the different programs. The control cards are color coded with explanations of their use written on each set.

The instructions for operating the digital computer and graphics display are already published and can be obtained from the Laboratory Office.

The following is a sequence of events and instructions for operating the simulator assuming all equipment is turned on.

1. Load the version of tape selected on the tape drives. Select the proper mount (2 for SI, 3 for RERUN).
2. Load and ready the card reader with control cards followed by the DATA.
3. Ready the Line Printer.
4. On the Digital Main Frame, Punch IDLE, RESET, RUN, CARDS.

Cards and tape should start being read at this time.

5. Load the Analog Program board and the Analog Logic board into the computer (Boards number 7).
6. On the Analog Keyboard punch KEYBOARD, LOCAL, POTSET. In the far right control box, only the following can be lit: IDCX1 or IDCX.1 and REAL TIME. All other lights must be punched out. When complete punch DIGITAL CMPTR.
7. On the Analog the following options exist:
 - DS0 - UP - no printed output
 - CENTER - printed output
 - DS1 - UP - distance integrators disabled
 - CENTER - distance integrators enabled
 - DS2 - UP - yaw damper ON
 - CENTER - yaw damper OFFDOWN positions on these switches are momentary contact positions.
8. On the Analog:

Turn the inner dials of DF12 and DF13 clockwise until resistance is felt. Then set the outer dial of DF12 to .1 and the outer dial of DF13 to 10.
9. Under Master Clock (Analog) punch RUN. The run light on the light panel should be on and the DF13 light should be flashing.
10. At the Graphics terminal teletype to be used (usually number 2), load the controlling program by typing
 - RESET ("GATD1", 120) !If the above is answered with
 - FILE NOT FOUNDtype
 - RESET ("GATD1", 20)!Then execute the program by typing GATED! At this point nothing should be on the display screen.

11. By this time the Digital computer should have compiled and loaded the main program and the following will be typed out on the Digital consol teletype:

INPUT AGT NUMBER

The input light will then come on. To respond, type the AGT number (1 or 2) of the unit being used, followed by a carriage return.

12. The Title should appear on the selected AGT.
13. The Data will be read in from the card reader.
14. If output is selected, the output will be printed on the line printer.
15. The Analog Pots will be set by the Digital computer. The Address and Ratiometer readings should be changing.
16. Set the cockpit in front of the AGT (will only reach AGT-2).
The cockpit is stored behind the Analog computer.
17. The Instructions should flash on the screen.
18. Punch the button on the Throttle plate and the display will appear.
19. Punch the button on the control stick to fly. If during a run you wish to abort that run, punch the button on the Throttle plate.
20. At the completion of the run the Landing Results will be displayed, followed by a short delay in which to read them.
21. At this time two options are offered. To fly again punch the button on the Control stick and the program jumps back to the Instructions (#17).

22. To receive the expanded program options, punch the Throttle button. Follow the displayed instructions and type your selection on the AGT teletype unit. This will result in one of three things happening.
 1. Logical STOP to the program.
 2. Jump to the Instructions (#17).
 3. Jump to the selection of the AGR number (#11).
23. At the completion of the computer time. Return all used equipment (cards, tape, boards, cockpit) to their storage locations.

APPENDIX F - PREPARATION OF DATA DECK

The following is a guide to be used in preparing the data deck to be used with the simulator.

Cards 1 - 6 - The first six data cards consist of the actual coordinates of the six runway points. The first ten columns of the card are the x coordinate in feet, the second ten columns are the y coordinate in feet, the third ten columns are the z coordinate in feet and the next ten columns are the H-Matrix scale factor which in this simulator is 1.0. The remaining columns are left blank. The order of the runway points is as follows: far-centerline, far-left, near-left, near-centerline, near-right, far-right.

Card 7 - The first ten columns consist of the optimum glide slope (GS0) in degrees. The second ten columns contain the x coordinate of the location of the Fresnel Lens (XMIR) in feet. The third ten columns contain the velocity of the headwind (WIND) in knots.

Card 8 - 10 - These cards contain the inputted scale factors for the scaling of the analog solution. Each scale factor has a field of ten columns and are ordered as follows:

Card 8 - SF1, SF2, SF3, SF4, SF5, SF6, SF8, SF9

Card 9 - SF10, SF11, SF12, SF13, SF14, SF15, SF16, SF17

Card 10 - SF18, SF19, SF30, the remaining columns are blank

Card 11 - This card contains the initial conditions of the problem in ten column increments as follows: initial x coordinate (SX0) in feet, initial altitude (SZ0) in feet, initial velocity (V0) in ft/sec, initial angle of attack (A10) in degrees, initial elevator angle (DIT0) in degrees and the density of the air (RHO) in slug/ft³. The remaining portion of the card is left blank.

Card 12 - This card contains a portion of the aircraft constants again in ten column intervals. They are as follows: weight (W) of the aircraft in lb, wing span (B) in ft, wing chord (CB) in ft, wing area (S) in ft^2 , moment of inertia about the x axis (RIXX) in slug-ft^2 , moment of inertia about the y axis (RIYY) in slug-ft^2 , moment of inertia about the z axis (RIZZ) in slug-ft^2 , and the cross product of inertia (RIXZ) in slug-ft^2 .

Card 13 - This card contains some more aircraft constants again in ten column intervals. They are as follows: maximum thrust (T) in lbs, optimum/landing angle of attack (AOALDG) in degrees, height of eye at touchdown (SZF) in feet. The remaining columns are left blank.

Cards 14 - 85 (Alternating) - These cards contain the aerodynamic coefficients dependent on both alpha and beta. The first card in the series is as follows: in columns 1-2 the coefficient number, columns 3-4 blank, column 5 the index on beta (IB), columns 6-10 blank. On the remaining portion of the card in ten column intervals are the coefficients indexed on alpha (IA). The second card in the series also contains the remaining coefficients again in ten column intervals and indexed on alpha. Alpha is indexed 15 times for each beta index while beta is indexed 9 times for each of the four coefficients. The range on alpha is -25 degrees to + 45 degrees with 5 degree intervals while the range on beta is -40 degrees to +40 degrees with 10 degree intervals.

The coefficients are as follows:

| <u>Number</u> | <u>Coefficient</u> |
|---------------|--------------------|
| 1 | C_l |
| 2 | C_m |
| 3 | C_n |
| 4 | C_Y |

Cards 86 - 125 (Alternating) - These cards contain the aerodynamic coefficients dependent only on alpha. The first card in the series is as follows: columns 1-2 the coefficient number, columns 3-10 blank. The remaining portion of the card in ten column intervals are the aerodynamic coefficients indexed on alpha. The second card of the series contains the remaining coefficients again in ten column intervals and indexed on alpha. Alpha is indexed 15 times for each of the coefficients. A list of the remaining coefficients and their numbers is given below.

| <u>Number</u> | <u>Coefficient</u> |
|---------------|---------------------|
| 5 | C_D |
| 6 | C_L |
| 7 | $C_{L_{\delta it}}$ |
| 8 | $C_{m_{\delta it}}$ |
| 9 | $C_{Y_{\delta r}}$ |
| 10 | $C_{l_{\delta r}}$ |
| 11 | $C_{n_{\delta r}}$ |
| 12 | $C_{Y_{\delta a}}$ |
| 13 | $C_{l_{\delta a}}$ |
| 14 | $C_{n_{\delta a}}$ |
| 15 | C_{Y_p} |
| 16 | C_{l_p} |
| 17 | C_{n_p} |
| 18 | C_{Y_R} |
| 19 | C_{l_R} |

| <u>Number</u> | <u>Coefficient</u> |
|---------------|--------------------|
| 20 | C_{n_R} |
| 21 | C_{L_Q} |
| 22 | C_{m_Q} |
| 23 | C_{L_α} |
| 24 | C_{m_α} |

APPENDIX G - SAMPLE OUTPUT

The following is a sample output of the digital program and contains the following sections:

1. Runway Constants
2. Scale Factors and Aircraft Constants
3. Original Aircraft Aerodynamic Coefficients
4. Usable Aircraft Aerodynamic Coefficients
5. Pot Settings for the Analog Computer
6. Output of the Amplifiers and D/A Trunks

RUNWAY CONSTANTS

| POINT | X | Y | Z |
|-------|--------|--------|----|
| 1 | .0 | .0 | .0 |
| 2 | .0 | -100.0 | .0 |
| 3 | 8000.0 | -100.0 | .0 |
| 4 | 8000.0 | .0 | .0 |
| 5 | 8000.0 | 100.0 | .0 |
| 6 | .0 | 100.0 | .0 |

XMIR = 7300.000

HMIR = 6.530

GS6 = - 3.250

RAMP = 8000.000

W1 = 7674.327

W2 = 7641.327

W3 = 7608.327

W4 = 7575.327

| | | |
|--------|---|----------|
| SF1 | = | 400.000 |
| SF2 | = | 400.000 |
| SF3 | = | 400.000 |
| SF4 | = | 2.000 |
| SF5 | = | 2.000 |
| SF6 | = | 2.000 |
| SF7 | = | 20.000 |
| SF8 | = | 45.000 |
| SF9 | = | 45.000 |
| SF10 | = | 85.000 |
| SF11 | = | 85.000 |
| SF12 | = | 85.000 |
| SF13 | = | 3000.000 |
| SF14 | = | 4000.000 |
| SF15 | = | 2000.000 |
| SF16 | = | 10.000 |
| SF17 | = | 5.000 |
| SF18 | = | 5.000 |
| SF19 | = | 400.000 |
| SF20 | = | 200.000 |
| SF21 | = | 1.000 |
| SF22 | = | 200.000 |
| SF23 | = | 200.000 |
| SF24 | = | 200.000 |
| SF25 | = | 1.000 |
| SF26 | = | 1.000 |
| SF27 | = | 4.000 |
| SF28 | = | 4.000 |
| SF29 | = | 4.000 |
| A9ALDG | = | 10.000 |

| | | |
|------|---|-----------|
| SF30 | = | 1.000 |
| SF31 | = | .025 |
| SF32 | = | .025 |
| SF33 | = | 1.000 |
| SF34 | = | 1.000 |
| SF35 | = | 2.546 |
| SF36 | = | 2.546 |
| SF37 | = | 1.348 |
| SF38 | = | 1.348 |
| SF39 | = | 1.348 |
| SF40 | = | .050 |
| SX0 | = | 28000.000 |
| SZ0 | = | 1200.000 |
| VO | = | 250.000 |
| A10 | = | 4.510 |
| D1T0 | = | -3.410 |
| RH0 | = | .00238 |
| WIND | = | 10.000 |
| W | = | 18085.000 |
| B | = | 38.730 |
| CB | = | 10.840 |
| S | = | 375.000 |
| R1XX | = | 12645.000 |
| R1YY | = | 58295.000 |
| R1ZZ | = | 65754.000 |
| R1XZ | = | -208.000 |
| T | = | 10000.000 |
| SZF | = | 12.000 |

ORIGINAL COEF ARRAY

COEFFICIENT NUMBER 1

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|----------|----------|----------|----------|----------|-----------|-----------|-----------|-----------|
| -25.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| -20.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| -15.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| -10.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| -5.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| .0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 5.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 10.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 15.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 20.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 25.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 30.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 35.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 40.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |
| 45.0 | .0965599 | .0724199 | .0482800 | .0241400 | .0000000 | -.0241400 | -.0482800 | -.0724199 | -.0965599 |

ORIGINAL COEF ARRAY

COEFFICIENT NUMBER 2

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|
| -25.0 | .2639960 | .2639960 | .2639960 | .2639960 | .2639960 | .2639960 | .2639960 | .2639960 | .2639960 |
| -20.0 | .2108960 | .2108960 | .2108960 | .2108960 | .2108960 | .2108960 | .2108960 | .2108960 | .2108960 |
| -15.0 | .1577960 | .1577960 | .1577960 | .1577960 | .1577960 | .1577960 | .1577960 | .1577960 | .1577960 |
| -10.0 | .1046961 | .1046961 | .1046961 | .1046961 | .1046961 | .1046961 | .1046961 | .1046961 | .1046961 |
| -5.0 | .0515961 | .0515961 | .0515961 | .0515961 | .0515961 | .0515961 | .0515961 | .0515961 | .0515961 |
| .0 | -.0015038 | -.0015038 | -.0015038 | -.0015038 | -.0015038 | -.0015038 | -.0015038 | -.0015038 | -.0015038 |
| 5.0 | -.0546038 | -.0546038 | -.0546038 | -.0546038 | -.0546038 | -.0546038 | -.0546038 | -.0546038 | -.0546038 |
| 10.0 | -.1077037 | -.1077037 | -.1077037 | -.1077037 | -.1077037 | -.1077037 | -.1077037 | -.1077037 | -.1077037 |
| 15.0 | -.1608037 | -.1608037 | -.1608037 | -.1608037 | -.1608037 | -.1608037 | -.1608037 | -.1608037 | -.1608037 |
| 20.0 | -.2139037 | -.2139037 | -.2139037 | -.2139037 | -.2139037 | -.2139037 | -.2139037 | -.2139037 | -.2139037 |
| 25.0 | -.2670036 | -.2670036 | -.2670036 | -.2670036 | -.2670036 | -.2670036 | -.2670036 | -.2670036 | -.2670036 |
| 30.0 | -.3201036 | -.3201036 | -.3201036 | -.3201036 | -.3201036 | -.3201036 | -.3201036 | -.3201036 | -.3201036 |
| 35.0 | -.3732036 | -.3732036 | -.3732036 | -.3732036 | -.3732036 | -.3732036 | -.3732036 | -.3732036 | -.3732036 |
| 40.0 | -.4263036 | -.4263036 | -.4263036 | -.4263036 | -.4263036 | -.4263036 | -.4263036 | -.4263036 | -.4263036 |
| 45.0 | -.4794036 | -.4794036 | -.4794036 | -.4794036 | -.4794036 | -.4794036 | -.4794036 | -.4794036 | -.4794036 |

ORIGINAL COEF ARRAY

COEFFICIENT NUMBER 3

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|-----------|-----------|-----------|-----------|----------|----------|----------|----------|----------|
| -25.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| -20.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| -15.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| -10.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| -5.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| .0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 5.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 10.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 15.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 20.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 25.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 30.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 35.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 40.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |
| 45.0 | -.1119199 | -.0839400 | -.0559600 | -.0279800 | .0000000 | .0279800 | .0559600 | .0839400 | .1119199 |

ORIGINAL COEF ARRAY

COEFFICIENT NUMBER 4

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|-----------|----------|----------|----------|----------|-----------|-----------|-----------|------------|
| -25.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| -20.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| -15.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| -10.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| -5.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| .0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 5.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 10.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 15.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 20.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 25.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 30.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 35.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 40.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |
| 45.0 | 1.0015993 | .7511999 | .5007999 | .2503999 | .0000000 | -.2503999 | -.5007999 | -.7511999 | -1.0015993 |

ORIGINAL COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 5 | COEFFICIENT NUMBER 6 | COEFFICIENT NUMBER 7 | COEFFICIENT NUMBER 8 | COEFFICIENT NUMBER 9 |
|-------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| -25.0 | .0789612 | -1.3319769 | .0110000 | -.0145000 | .0045000 |
| -20.0 | .0911161 | -.9919785 | .0110000 | -.0145000 | .0045000 |
| -15.0 | .1032711 | -.6519783 | .0110000 | -.0145000 | .0045000 |
| -10.0 | .1154261 | -.3119794 | .0110000 | -.0145000 | .0045000 |
| -5.0 | .1275811 | .0280204 | .0110000 | -.0145000 | .0045000 |
| .0 | .1397361 | .3680202 | .0110000 | -.0145000 | .0045000 |
| 5.0 | .1518911 | .7080200 | .0110000 | -.0145000 | .0045000 |
| 10.0 | .1640461 | 1.0480194 | .0110000 | -.0145000 | .0045000 |
| 15.0 | .1762011 | 1.3880196 | .0110000 | -.0145000 | .0045000 |
| 20.0 | .1883562 | 1.7280188 | .0110000 | -.0145000 | .0045000 |
| 25.0 | .2005111 | 2.0680180 | .0110000 | -.0145000 | .0045000 |
| 30.0 | .2126661 | 2.4080172 | .0110000 | -.0145000 | .0045000 |
| 35.0 | .2248211 | 2.7480173 | .0110000 | -.0145000 | .0045000 |
| 40.0 | .2369761 | 3.0880175 | .0110000 | -.0145000 | .0045000 |
| 45.0 | .2491311 | 3.4280167 | .0110000 | -.0145000 | .0045000 |

ORIGINAL COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 10 | COEFFICIENT NUMBER 11 | COEFFICIENT NUMBER 12 | COEFFICIENT NUMBER 13 | COEFFICIENT NUMBER 14 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| -20.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| -15.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| -10.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| -5.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| .0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 5.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 10.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 15.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 20.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 25.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 30.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 35.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 40.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |
| 45.0 | .0005021 | --.0019800 | .0025500 | --.0029950 | --.0008237 |

ORIGINAL C9EF ARRAYS

| ALPHA | C9EFFICIENT NUMBER 15 | C9EFFICIENT NUMBER 16 | C9EFFICIENT NUMBER 17 | C9EFFICIENT NUMBER 18 | C9EFFICIENT NUMBER 19 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| -20.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| -15.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| -10.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| -5.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| .0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 5.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 10.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 15.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 20.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 25.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 30.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 35.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 40.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |
| 45.0 | .1436000 | --.3550000 | --.1117000 | .4559000 | .1328000 |

ORIGINAL COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 20 | COEFFICIENT NUMBER 21 | COEFFICIENT NUMBER 22 | COEFFICIENT NUMBER 23 | COEFFICIENT NUMBER 24 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| -20.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| -15.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| -10.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| -5.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| .0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 5.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 10.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 15.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 20.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 25.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 30.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 35.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 40.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |
| 45.0 | --3469999 | .0000000 | -3.89999996 | .0000000 | --7490000 |

USABLE COEF ARRAY

COEFFICIENT NUMBER 1

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|-----------|-----------|-----------|-----------|----------|------------|------------|------------|------------|
| -25.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| -20.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| -15.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| -10.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| -5.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| .0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 5.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 10.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 15.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 20.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 25.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 30.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 35.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 40.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |
| 45.0 | 5.5453217 | 4.1589898 | 2.7726637 | 1.3863319 | .0000000 | -1.3863319 | -2.7726637 | -4.1589898 | -5.5453217 |

USABLE COEFF ARRAY

COEFFICIENT NUMBER 2

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|------------|------------|------------|------------|------------|------------|------------|------------|------------|
| -25.0 | .9204424 | .9204424 | .9204424 | .9204424 | .9204424 | .9204424 | .9204424 | .9204424 | .9204424 |
| -20.0 | .7353051 | .7353051 | .7353051 | .7353051 | .7353051 | .7353051 | .7353051 | .7353051 | .7353051 |
| -15.0 | .5501679 | .5501679 | .5501679 | .5501679 | .5501679 | .5501679 | .5501679 | .5501679 | .5501679 |
| -10.0 | .3650310 | .3650310 | .3650310 | .3650310 | .3650310 | .3650310 | .3650310 | .3650310 | .3650310 |
| -5.0 | .1798938 | .1798938 | .1798938 | .1798938 | .1798938 | .1798938 | .1798938 | .1798938 | .1798938 |
| .0 | -.0052431 | -.0052431 | -.0052431 | -.0052431 | -.0052431 | -.0052431 | -.0052431 | -.0052431 | -.0052431 |
| 5.0 | -.1903803 | -.1903803 | -.1903803 | -.1903803 | -.1903803 | -.1903803 | -.1903803 | -.1903803 | -.1903803 |
| 10.0 | -.3755172 | -.3755172 | -.3755172 | -.3755172 | -.3755172 | -.3755172 | -.3755172 | -.3755172 | -.3755172 |
| 15.0 | -.5606545 | -.5606545 | -.5606545 | -.5606545 | -.5606545 | -.5606545 | -.5606545 | -.5606545 | -.5606545 |
| 20.0 | -.7457917 | -.7457917 | -.7457917 | -.7457917 | -.7457917 | -.7457917 | -.7457917 | -.7457917 | -.7457917 |
| 25.0 | -.9309286 | -.9309286 | -.9309286 | -.9309286 | -.9309286 | -.9309286 | -.9309286 | -.9309286 | -.9309286 |
| 30.0 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 | -1.1160658 |
| 35.0 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 | -1.3012030 |
| 40.0 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 | -1.4863403 |
| 45.0 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 | -1.6714775 |

USABLE COEF ARRAY

COEFFICIENT NUMBER 3

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|---------------|------------|-----------|-----------|-----------|----------|----------|----------|----------|-----------|
| -25.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| -20.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| -15.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| -10.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| -5.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| .0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 5.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 10.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 15.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 20.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 25.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 30.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 35.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 40.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |
| 45.0 | -1.2360439 | -.9270338 | -.6180225 | -.3090113 | .0000000 | .3090113 | .6180225 | .9270338 | 1.2360439 |

USABLE COEF ARRAY

COEFFICIENT NUMBER 4

| BETA ALPHA | -40.0 | -30.0 | -20.0 | -10.0 | .0 | 10.0 | 20.0 | 30.0 | 40.0 |
|------------|-----------|-----------|-----------|-----------|----------|------------|------------|------------|------------|
| -25.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| -20.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| -15.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| -10.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| -5.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| .0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 5.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 10.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 15.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 20.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 25.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 30.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 35.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 40.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |
| 45.0 | 6.6874822 | 5.0156145 | 3.3437428 | 1.6718710 | .0000000 | -1.6718710 | -3.3437428 | -5.0156145 | -6.6874822 |

USABLE COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 5 | COEFFICIENT NUMBER 6 | COEFFICIENT NUMBER 7 | COEFFICIENT NUMBER 8 | COEFFICIENT NUMBER 9 |
|-------|----------------------------|----------------------------|----------------------------|----------------------------|----------------------------|
| -25.0 | -0.5272085 | 8.89333487 | -0.7344484 | -0.5055536 | 0.1502281 |
| -20.0 | -0.6083643 | 6.6232460 | -0.7344484 | -0.5055536 | 0.1502281 |
| -15.0 | -0.6895209 | 4.3531313 | -0.7344484 | -0.5055536 | 0.1502281 |
| -10.0 | -0.7706774 | 2.0830253 | -0.7344484 | -0.5055536 | 0.1502281 |
| -5.0 | -0.8518340 | -0.1870267 | -0.7344484 | -0.5055536 | 0.1502281 |
| 0 | -0.9329905 | -2.4571987 | -0.7344484 | -0.5055536 | 0.1502281 |
| 5.0 | -1.0141471 | -4.7273108 | -0.7344484 | -0.5055536 | 0.1502281 |
| 10.0 | -1.0953037 | -6.9974201 | -0.7344484 | -0.5055536 | 0.1502281 |
| 15.0 | -1.1764602 | -9.2675348 | -0.7344484 | -0.5055536 | 0.1502281 |
| 20.0 | -1.2576174 | 11.5376428 | -0.7344484 | -0.5055536 | 0.1502281 |
| 25.0 | -1.3387733 | 13.8077508 | -0.7344484 | -0.5055536 | 0.1502281 |
| 30.0 | -1.4192299 | 16.0778588 | -0.7344484 | -0.5055536 | 0.1502281 |
| 35.0 | -1.5010864 | 18.3479728 | -0.7344484 | -0.5055536 | 0.1502281 |
| 40.0 | -1.5822430 | 20.6180875 | -0.7344484 | -0.5055536 | 0.1502281 |
| 45.0 | -1.6633995 | 22.8881956 | -0.7344484 | -0.5055536 | 0.1502281 |

USABLE COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 10 | COEFFICIENT NUMBER 11 | COEFFICIENT NUMBER 12 | COEFFICIENT NUMBER 13 | COEFFICIENT NUMBER 14 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| -20.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| -15.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| -10.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| -5.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| .0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 5.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 10.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 15.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 20.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 25.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 30.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 35.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 40.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |
| 45.0 | .1441751 | -.1093356 | .0851293 | -.8599967 | -.0454847 |

USABLE COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 15 | COEFFICIENT NUMBER 16 | COEFFICIENT NUMBER 17 | COEFFICIENT NUMBER 18 | COEFFICIENT NUMBER 19 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| -20.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| -15.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| -10.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| -5.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| .0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 5.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 10.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 15.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 20.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 25.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 30.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 35.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 40.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |
| 45.0 | .0047939 | --.1019362 | --.0061681 | .0152198 | .0381327 |

USABLE COEF ARRAYS

| ALPHA | COEFFICIENT NUMBER 20 | COEFFICIENT NUMBER 21 | COEFFICIENT NUMBER 22 | COEFFICIENT NUMBER 23 | COEFFICIENT NUMBER 24 |
|-------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|-----------------------------|
| -25.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| -20.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| -15.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| -10.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| -5.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| .0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 5.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 10.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 15.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 20.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 25.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 30.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 35.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 40.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |
| 45.0 | --.0191613 | .0000000 | --.0679882 | .0000000 | --.0130572 |

POT SETTINGS

| | | | | | |
|---------|---|---------|---------|---|---------|
| POT(0) | = | • 01645 | POT(24) | = | • 13481 |
| POT(1) | = | • 05899 | POT(25) | = | • 25465 |
| POT(2) | = | • 20000 | POT(26) | = | • 25465 |
| POT(3) | = | • 00357 | POT(27) | = | • 13481 |
| POT(4) | = | • 09110 | POT(30) | = | • 13481 |
| POT(5) | = | • 20000 | POT(31) | = | • 05000 |
| POT(6) | = | • 00316 | POT(32) | = | • 62500 |
| POT(7) | = | • 06943 | POT(33) | = | • 95200 |
| POT(10) | = | • 20000 | POT(34) | = | • 17452 |
| POT(11) | = | • 10000 | POT(35) | = | • 18399 |
| POT(12) | = | • 10000 | POT(36) | = | • 00160 |
| POT(13) | = | • 32700 | POT(37) | = | • 23068 |
| POT(14) | = | • 28119 | POT(40) | = | • 09620 |
| POT(15) | = | • 02600 | POT(41) | = | • 28000 |
| POT(16) | = | • 93333 | POT(42) | = | • 10022 |
| POT(17) | = | • 50000 | POT(43) | = | • 22918 |
| POT(20) | = | • 60000 | POT(44) | = | • 34100 |
| POT(21) | = | • 01333 | POT(45) | = | • 10000 |
| POT(22) | = | • 10000 | POT(46) | = | • 00056 |
| POT(23) | = | • 20000 | POT(50) | = | • 00600 |

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| 13. ABSTRACT <p>The following is a report on the design and construction of a fixed-base variable-stability simulator facility combined with the task of landing to a carrier or runway.</p> <p>The solution was mechanized on a hybrid computer with the analog computer solving the equations of motion and the digital computer used for storage, control and graphics generation. The display was in the form of a computer drawn picture on a graphics terminal. Control was by a simulated cockpit placed in front of the display and connected to the analog computer.</p> <p>Dynamic validation was considered excellent with the modal periods of the simulated aircraft agreeing very closely with those of the actual aircraft.</p> <p>The visual display was deemed very good as sufficient visual cues were provided to enable consistent landings by experienced pilots.</p> <p>This project was undertaken not as a design of a training aid but rather as a research tool for further studies in control systems, human engineering and aircraft dynamics.</p> | | | |

| KEY WORDS | LINK A | | LINK B | | LINK C | |
|------------------------------|--------|----|--------|----|--------|----|
| | ROLE | WT | ROLE | WT | ROLE | WT |
| Landing Simulator | | | | | | |
| Aircraft Simulator | | | | | | |
| Simulator | | | | | | |
| Variable-Stability Simulator | | | | | | |
| Interactive Graphics | | | | | | |



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